# HAND-BOOK

TO DIAGRAMS IN

# LIGHT AND HEAT

BY

WILLIAM LEES, M.A.

LECTURER ON NATURAL PHILOSOPHY, EDINBURGH

## SHEET No. I.

## LIGHT (Part I.)

W. & A. K. JOHNSTON

EDINBURGH AND LONDON

1881

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# JOHNSTON'S

# ILLUSTRATIONS OF LIGHT AND HEAT.

## *LIGHT* (*PART I.*)

*N.B.*—The numbers of the paragraphs do not correspond with the numbers of the diagrams.

1. *Theories of Light.*—Two theories have been propounded as to the nature of Light. They are known as the "emission" theory and the "undulatory" theory. According to the former, light consists in the actual emanation of luminous particles from the luminous body; that these particles strike upon or enter our eyes, and excite the sensation of vision. The latter theory assumes the existence of an extremely subtle fluid, viz. *ether*, which pervades all space, and even the pores of bodies. A vibratory motion is supposed to be produced in this ether by the luminous body, in virtue of which a series of minute undulations or waves are propagated in all directions, and that it is by the shock or impact of these waves upon our eyes that vision is excited.

The "undulatory" theory is the one more generally accepted amongst modern physicists, as it is adapted to explain satisfactorily all the phenomena connected with light.

2. *Rectilinear Propagation of Light.*—That light proceeds in

*straight* lines is evident from the most familiar observation. Holding an opaque body in front of a visible object we lose sight of the object. Or again, in a darkened room, the track of a beam of sunlight through the chinks of the shutter, is perfectly straight.

3. *Formation of an Inverted Image through a small aperture.*—This is a consequence of the rectilinear propagation of light. If a small aperture be made in the door of a darkened chamber (fig. 1), and a well-illuminated object be situated outside, the rays proceed as the diagram shows, and an *inverted* image of it is cast upon the opposite wall. The inversion is caused by the crossing of the rays at the aperture. The configuration of the image is the same as that of the object, and is independent of the shape of the aperture.

4. *Umbra and Penumbra.*—Another consequence of the rectilinear propagation of light is the formation of a shadow. If the luminous origin be considered as a *point*, and an opaque body be placed in front of it, there is formed a shadow, or "umbra" *only*. But if the luminous origin be of sensible magnitude, as is the case in actual experience, then besides the umbra, there is formed a *partial* shadow, or "penumbra," as it is called. This is well exemplified in eclipses. Fig. 2 shows the position of the sun, moon, and earth during an eclipse of the sun. The moon's shadow is represented as covering a portion of the earth's surface; within this portion there is a *total* eclipse of the sun. But surrounding the umbra proper, there is also the penumbra; within the latter there would only be a *partial* eclipse of the sun. It sometimes happens that the moon's shadow falls short of the earth. This occurs when the earth in her orbit comes near the sun, and at the same time when the moon in her orbit is at her greatest distance from the earth. In this case an "annular" eclipse takes place—the moon is seen projected on the face of the sun, with a white ring encircling her.

5. *Law of Intensity.*—The intensity of light diminishes with the distance, according to a certain law. What that law is will be understood by reference to fig. 3. Suppose a board to be placed at the distance of *one* foot from a lamp *L*, and that a certain quantity of light covers a part of it, viz. *A B*—*A B* is illuminated with a certain intensity. If removed to the distance of *two* feet, the same light (owing to its divergence) would now cover a space, *C D*, four times as great as *A B;* and if removed to the distance of *three* feet, that light would cover a surface, *E F*, nine times as great. It is clear, therefore, that the *intensity* at *two* feet is one-fourth, and the intensity at *three* feet one-ninth, of that at *one* foot. If the distances be 1, 2, 3, 4, etc., the intensities will then be expressed by 1, $\frac{1}{4}$, $\frac{1}{9}$, $\frac{1}{16}$, etc. This is called the law of *inverse* squares. It may be fully enunciated thus: *The intensity of light from any luminous source is inversely proportional to the square of the distance.*

6. *Photometer.*—There have been several instruments devised for the measurement of light. Such instruments are called "photometers." One of these is represented in fig. 4. It is known as Bunsen's photometer, and is much used to test the illuminating power or quality of gas. It consists of a brass stand graduated in feet and inches, on which is placed a movable screen with an oil spot in the centre. The lights to be compared are set at the ends of the scale, and the screen is then moved until the oil spot appears *equally* bright from either side. The distances of the lights from the screen are then noted, and the intensities determined from the fact (easily deducible from the foregoing law) that they are *directly proportional to the squares of these distances.* Thus suppose the distances of the lamp and candle to be respectively 5 feet and 3 feet, then the intensities are as 25 to 9; in other words, the gas will give $2\frac{7}{9}$ as much light as the candle.

The principle of the instrument is as follows: When the screen is viewed by *transmitted* light from one source, more light

passes through the oiled part than through the rest of the screen; the spot, therefore, looks brighter. When viewed by *reflected* light, on the other hand, less light is reflected from the oil spot than from the rest of the screen; the spot, therefore, looks darker. But when two lights are used, and the screen adjusted so that the spot appears equally bright with the rest of the screen, from whichever side it is viewed, it indicates that as much light is transmitted through the oil spot by the gas-jet as by the candle.

An improvement on this instrument has been made by Dr. Letheby. The scale is set vertically, and the screen is enclosed in a box open at both ends, and having an aperture through which the screen is viewed by reflection from two plane mirrors inside. The box is mounted on wheels, and can be readily moved along the scale.

Another modification is "Evans'" system, which does not require a dark room, and may be used even in the open air.

Both of these improved forms are being largely introduced into gas companies both at home and abroad.

7. *Velocity of Light.*—The velocity of light was first determined by Rœmer in 1675. He deduced it from observations on the eclipses of the third satellite of Jupiter. He observed that an eclipse took place about fifteen minutes sooner when the earth was at $E$ than when at $E'$ (fig. 5), and this he accounted for thus: that the last glimpse of light sent off by the satellite $M$, previous to its passing into Jupiter's shadow, took that interval of time to cross the earth's orbit. From this he calculated the velocity to be 192,500 miles per second.

Experiments made in France and elsewhere over carefully measured terrestrial distances, reduce this estimate to about 185,000 miles per second.

A velocity of this kind is so prodigious as to need comparison with velocities with which we are more familiar. Whilst light takes about seven and a half minutes to travel from the sun to the earth, an express train going at the rate of forty miles an

hour, would require 265 years to perform the journey, and a cannon-ball fired from the earth, and retaining its initial velocity of projection, would reach the sun in about nine and two-third years.

8. *Reflexion of Light.*—Objects are rendered visible by the power they possess of reflecting the light which falls upon them. The light is reflected *irregularly*, or scattered. On the other hand, if a beam of light impinge upon a common looking-glass, after reflexion it is sent off in a particular course. Let $A$ $B$ be a ray of light falling upon the mirror $M$ (fig. 6), and $B$ $D$ a perpendicular drawn from $B$, it is reflected in such a direction $B$ $C$ as that the angle $A$ $B$ $D$ is always equal to the angle $C$ $B$ $D$. The beam is reflected *regularly*. The angle $A$ $B$ $D$ is known as the angle of *incidence*, and $C$ $B$ $D$ as the angle of *reflexion*. In regular reflexion, therefore, the *angle of reflexion is equal to the angle of incidence*. Such is the law of *regular* reflexion.

9. *Image formed by a Plane Mirror.*—When an object is placed in front of a plane mirror, its image is seen *as far behind* the mirror as the object itself is before it. This is founded upon the previous law, and may be easily proved, by geometry.

Fig. 7 shows the position of the image in reference to the object.

If a mirror be moved to or from an object, the space through which the image is moved is *twice* the space through which the mirror moves. Thus if a person stand before a mirror, and the mirror be moved one foot towards him, his image moves over two feet. This is easily proved from the principle stated at the beginning of this paragraph.

Some experiments with a plane mirror are worthy of being mentioned. (1) Hold a pencil *upright* before the mirror set at an angle of 45° with the horizon, the image of the pencil is seen in a horizontal position. Again, hold the pencil horizontally, the image is seen in a vertical position. (2) In a dark room place a candle before the mirror; if the eye be situated immediately

behind the candle, *one* image of the candle only is seen; but move the candle out of the line of vision, a series of images is formed. The second in the series is the brightest, and results from the reflexion of the silvered surface behind, whilst the other images are caused by *repeated* reflexions from surface to surface of the glass. (3) An individual may see his whole person in a mirror which is *half* his length.

10. *Lateral Inversion.*—If a person stand before a plane mirror, his *right* eye will be observed to be the *left* in the image, and his *left* eye the *right* in the image. This effect in a mirror is called "lateral inversion." Hence writing written *backwards* is adjusted by being held before a mirror; so also types set for printing when similarly held can be read off, as on the printed page.

Fig. 8 shows how the word LIGHT when printed in the ordinary way and backwards would appear by reflexion in a plane mirror.

11. *Reflexion by two Plane Mirrors.*—When two mirrors are set at right angles to each other, and an object be placed between them, *three* images of the object are formed. Two of these are formed by direct reflexion from the mirrors; the third is the result of a *double* reflexion.

Fig. 9. shows this clearly.

It will be observed that the object and its three images are in the angles of a rectangle. If the object be placed at *equal* distances from the mirrors, the figure, formed by joining the images and object, is a square. If the angle between the mirrors be 60°, five images are formed; if the angle be 45°, there are seven images; and if it be 30°, eleven images. In such cases, suppose the object to be placed at *equal* distances between the mirrors, then the object and its images are disposed at the angles of a *regular* polygon of six, eight, and twelve sides respectively.

If the mirrors be *parallel*, the number of images is infinite (theoretically), but practically, the images in the end become so

feeble, from multiple reflexion, as to cease to be visible. An arrangement of this kind is sometimes called the "endless gallery," and is used in ballrooms, picture-galleries, jewellers' shops, and the like, in order to enhance their appearance and produce a dazzling effect.

12. *Kaleidoscope.*—This is an instrument, as its name implies, for *seeing beautiful forms or designs.* It depends for its action upon the symmetrical disposition or arrangement of images produced by two plane reflectors.

Fig. 10 represents an excellent form of it.

Inside the tube are placed two *smoked* pieces of glass (which serve as the reflectors) set at angle of 30°. The objects are pieces of coloured glass, beads, and small tubes partly filled with fluid of different colours; these are enclosed loosely between two glass plates, and are adjusted at the *end* of the tube, so as to be moved into different positions by small projecting pins. The whole is mounted upon a stand for convenience' sake. Looking in through a small aperture at the other end of the tube, and slowly moving round the "object" glass, a great variety of beautiful figures or designs is seen. The fluid in the small tubes as it moves from one end to the other, according as their position is varied by the rotation of the object glass, is a striking feature in this form of the instrument.

The number of different designs obtained is practically endless; indeed, the chance of seeing precisely the *same* design again as the object glass is rotated amounts almost to an impossibility.

The designer of "patterns" may derive important hints, therefore, from such an instrument as this.

13. *Image formed by a Concave Mirror.*—Fig. 11 shows how an image is formed by a concave spherical mirror.

Let a line $C\ D$ be drawn at right angles to the mirror $M$ through the centre of curvature $O$; this line is called the *principal* axis of the mirror. If the sun's rays fall upon the

mirror they are chiefly concentrated in the point *F*, nearly midway between the centre of curvature and the mirror; this point is called the *principal* focus. It may be defined as the point *where parallel rays are concentrated.* If *divergent* rays, proceeding from a luminous source beyond the centre of curvature, fall upon the mirror, the focus of the rays is formed between the principal focus and the centre of curvature. If the luminous origin coincide with the point *O*, the rays are reflected directly back, and there is no focus.

In the diagram (fig. 11, *a*) *A B* is an object placed beyond the centre of curvature. The rays from *A* after reflexion are concentrated at *A′*, and those from *B* at *B′*, whilst the rays from intermediate points between *A* and *B* are concentrated at corresponding points between *A′* and *B′*. Thus an image of *A B* is formed at *A′ B′*; this image is inverted, and is smaller than the object. Moreover, it is a *real* image; in other words, the rays from *A B* after reflexion by the mirror are actually concentrated into foci, and form the image *A′ B′*.

In the diagram (fig. 11, *b*) if the object *A B* be placed *between* the principal focus *F* and the mirror, then the rays after reflexion enter the eye of a spectator, and produce the impression as if they came from an object *A′ B′* *behind* the mirror. An image of *A B* is therefore seen there; it is larger than the object, and is erect. This image is called a *virtual* image; it is an imaginary one, as in the case of a plane mirror.

These results can be experimentally proved by using a concave mirror. Holding the mirror at arms' length (if it have sufficient concavity) in front of the face, an inverted image of the face is seen; moving the mirror towards the person, the image is seen larger and larger until it disappears altogether. At the moment of disappearance the position of the face coincides with the centre of curvature. When moved *past* the principal focus an enlarged erect image is seen, which increases in size as the mirror is moved towards the face.

14. *Image formed by a Convex Mirror.*—Fig. 12 shows how an image is formed by a convex spherical mirror.

*A B* is an object placed before such a mirror. The rays from *A* after reflexion enter the eye as if they came from *A′*, and those from *B* as if they came from *B′*. The same is true of intermediate points. Thus an image of *A B* is seen at *A′ B′*. It is smaller than the object, and is a *virtual* image. The point *F* is the *principal* focus, that is, it is the point from which parallel rays after reflexion seem to diverge, to an eye placed in front of the mirror.

The image in this kind of mirror is always *erect*, but varies in size according to the distance of the object from the mirror. This can readily be proved by experiment.

15. *Refraction.*—A ray of light in passing from one medium into another—as, for example, from air into water—is said to be *refracted*, that is, it deviates from the course which it has been pursuing in air when it enters the water.

In fig. 13 let *A B* be a ray of light, *C B E* a perpendicular upon the surface of the water. The ray *A B* on entering the water takes the course *B D*; it is bent or refracted *towards* the perpendicular. The angle *A B C* is termed the angle of *incidence* (as before), and *D B E* the angle of *refraction.*

The precise law which regulates refraction will be understood from the diagram. Let a circle be described with *B* as a centre, and any radius *B A*; then drawing *A F* and *D G* parallel to the surface of the water, the course which the ray *A B* takes on entering the water is such that, when these lines are drawn, they bear the proportion of 4 to 3. This ratio may be expressed by the fraction $\frac{4}{3}$, and is called the *index of refraction* for air and water. For air and glass the index is $\frac{3}{2}$. Conversely, if a ray of light pass from water into air, the index is expressed by the fraction $\frac{3}{4}$, and from glass into air $\frac{2}{3}$.

It will be observed, therefore, that when a ray of light passes from a rare medium into a denser it is refracted *towards* the perpendicular; and conversely, when it passes from a dense

medium into a rarer it is refracted *from* the perpendicular. Such is the *general* deportment of a ray of light (with one or two exceptions).

Suppose a ray of light $D\ B$ to pass from water into air, it takes the direction $B\ A$; if the angle of incidence $D\ B\ E$ increase, the angle of refraction $C\ B\ A$ will also increase until the angle $D\ B\ E$ is such as that the angle $C\ B\ A$ becomes nearly a right angle. When this is the case the ray of light $D\ B$ passes out, and no more; the emergent ray becomes nearly parallel to the surface of the water. The angle $D\ B\ E$ is then found to be 48° 35′; it is called the *critical* or *limiting* angle of refraction. If the incident angle exceed this amount, the ray does not emerge from the water; it is reflected from the surface in the ordinary manner. As an illustration of this, take a plain tumbler and fill it with water; drop a shilling into it, and hold the tumbler in a sloping position. Looking through the tumbler towards the surface of the water, an image of the coin is seen suspended in the air.

16. *Phenomena due to Refraction.*—There are certain familiar facts which are easily explained by the refraction of light.

(1.) A pool of water (fig. 14, *a*) appears less deep than it really is. Thus the point $A$ at the bottom of the pool appears raised to $A'$, and the same is true of other points; thus the whole bottom appears lifted up. This lifting is the greater the more *oblique* the vision. We can understand, therefore, the danger of a person who cannot swim going into water which may appear shallow, but which is in reality beyond his depth.

(2.) A straight rod placed vertically in water appears shortened, and if placed obliquely (fig. 14, *b*) appears bent. The immersed part in either case seems *raised* by refraction.

(3.) The illegal practice of spearing salmon by torchlight, which used to be carried on, in some of our rivers, depended skill of the poacher directing his spear *below* where s seen.

(4.) In clear water the bottom of a boat is seen to be much flatter than it really is.

An interesting experiment on refraction is this: Place a coin in a bowl, and retire from it until the coin is lost sight of by the interposition of the edge; desire now a person to fill up the bowl with water, the coin again comes into view.

17. *Refraction is accompanied by Reflexion.*—Whenever there is refraction there is also reflexion. This explains why, on the bank of a lake, unruffled by wind, the images of objects on the opposite bank are seen reflected in the water and in an inverted position.

Fig. 15 shows this well-known phenomenon.

The dulness which is observable in the images is due to a large part of the rays of light from the objects entering the water, and of course suffering refraction. This dulness is the less the more oblique the vision of the spectator, for then a greater quantity of light is reflected—a striking instance of the effect of *obliquity* in reflexion.

18. *The Mirage.*—"The unusual elevation of islands, coasts, ships, etc., above the surface of the sea in certain states of the atmosphere has been long known. The image of a distant ship, for instance, has been seen suspended in the air, sometimes erect, sometimes inverted.

"These strange phenomena are observed from time to time on our own coasts, but are witnessed with greater frequency and more strikingly in the Arctic regions. Captain Scoresby, the famous Arctic navigator, is said to have recognised his father's ship by its inverted image in the air, though it had not actually appeared above the horizon.

"These effects are due to refraction, and occur when the atmosphere is warmer than the surface of the sea. The inferior layers of air, because of their contact with the surface of the sea, are denser than those above. The density of the successive layers, therefore, diminishing upwards, the rays of light from a ship *A*

*B* (fig. 16) in passing through them are refracted *from* the perpendicular, and at length becoming incident at angles greater than the *limiting* angle, are totally reflected at such points as *C* and *D*; in returning through the strata they are now gradually bent *towards* the perpendicular, and enter the eye of an observer at *E*, as if they came up from an object at *A′ B′*. Thus an image of the distant ship is seen suspended in the air. The inverted image sometimes seen is accounted for by supposing that the rays before they reached the eye *cross* each other.

"The term mirage was first applied to this class of phenomena by one of the members of Napoleon's expedition into Lower Egypt in 1798. During the march of the French army through the sandy deserts, it was frequently observed that the land seemed to be terminated at a certain distance by a general inundation. The distant villages appeared to be so many islands planted in the midst of the apparent flood, with inverted images of them beneath. These appearances are explained in a similar way, with this difference, that the strata of air in immediate contact with the warm, sandy plain have less density than those above; the rays, therefore, after total reflexion, enter the eye and produce an inverted image analogous to what occurs on the surface of a lake (fig. 15)" (Lees' Advanced Acoustics, Light and Heat).

19. *Twilight.*—The influence of the atmosphere in refracting and reflecting the sun's rays is strikingly seen in the phenomenon of "twilight."

In fig. 17 the rays from the sun, *S*, upon entering the atmosphere (represented as consisting of so many layers of air) are refracted by the different strata, and take a curvilinear course in reaching the earth. The rays enter the eye of a spectator as if they came along the tangent line, and an image of the sun is seen at *S′*. The effect is, therefore, to make the sun appear above the horizon whilst he is actually *below* it. Hence refraction tends to prolong the stay of the sun above the horizon; it hastens his rising and delays his setting. Even after he has disappeared below the

horizon his cheering beams are not at once quenched; for his rays continue to be refracted and reflected in sufficient quantity to produce the pleasing phenomenon of *twilight*, by which we pass with so easy a gradation, from the brightness and activity of day, to the darkness and stillness of night. In tropical countries the shortness of the twilight is due to the fact that the sun sinks below the horizon very rapidly, the angle his course makes with the horizon being nearly a right angle.

It will be seen, therefore, that the effect of refraction upon the heavenly bodies is to make them appear *higher* in the sky than they really are. The amount of lifting is greatest in the horizon, and diminishes rapidly towards the zenith, where it is zero. This results from variation in the *thickness* of the atmosphere the rays have to pass through, with the different altitudes, as will be understood by an inspection of the diagram.

20. *Lenses.*—A "lens" is a refracting medium, constructed generally of glass, having its bounding surfaces either both curved, or the one plain and the other curved.

Lenses are divided into two classes—(1) *Converging;* (2) *Diverging.*

Fig. 18 shows the different forms.

*A, B, C* are converging lenses, *D, E, F* diverging lenses. They are named (from the nature of their bounding surfaces), thus :—

| | |
|---|---|
| *A*, double convex. | *D*, double concave. |
| *B*, plano-convex. | *E*, plano-concave. |
| *C*, concavo-convex (or *meniscus*). | *F*, convexo-concave. |

It will be observed that a converging lens is *thicker* at the centre than at the exterior borders, and a diverging lens *thinner*. In this way the one kind may be readily distinguished from the other kind.

21. *Formation of Image by a Convex Lens.*—Fig. 19 shows how an image is formed by a double convex lens.

When such a lens is exposed to parallel rays, or such as proceed from the sun, it concentrates them into a certain point; this point, *F*, in the diagram is called the *principal* focus. The line drawn through the centre of the lens at right angles is the *principal* axis.

Let *A B* be an object. The rays from *A*, after passing through the lens *L*, are concentrated at *A′*, those from *B* at *B′*, whilst those from intermediate points between *A* and *B* are concentrated at corresponding points between *A′* and *B′*. Thus an image of *A B* is formed at *A′ B′*. The image is inverted and is *real*. In like manner, if *A′ B′* be the object, *A B* would represent the image. The image and the object are thus *interchangeable*. Hence the image may be either smaller or larger than the object.

22. *Spherical Aberration.*—The rays which fall upon the *marginal* parts of a lens, are not concentrated into the same focus, as those passing through the central part of the lens. This inability on the part of a lens to concentrate all the rays falling upon it into one focus, is called *spherical aberration*. It interferes much with the distinctness of the image; hence the marginal parts of a lens are generally covered with an opaque diaphragm. This is the case in a photographic camera.

23. *Formation of Image by a Concave Lens.*—Fig. 20 shows how an image is formed by a double concave lens.

Let *A B* be the object. The rays from *A*, after passing through the lens *L*, *diverge*, and enter the eye of the observer as if they came from *A′*, and those from *B* from *B′*. Thus an image of *A B* is formed at *A′ B′*. It is *smaller* than the object, and is an erect and *virtual* image.

It will be observed, therefore, that whilst a convex lens is analogous in its action to a concave mirror, a concave lens is analogous to a convex mirror.

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## *LIGHT* (*PART II.*)

*N.B.*—The numbers of the paragraphs do not correspond with the numbers of the diagrams.

1. *Camera Obscura.*—This instrument is represented in fig. 1. It consists of a sloping enclosed box, blackened inside, to prevent internal reflexion. It is mounted with a cubical box formed of two parts, which are capable of sliding one into the other. In this there is set a plane mirror, movable upon an axis. At the bottom of this box is placed a lens.

On directing the mirror to a distant landscape (lit up with good sunlight), the rays of light proceeding from it which enter the small box are reflected by the mirror down upon the lens, which concentrates these rays into foci on a sheet of paper at the bottom of the instrument, and a faithful picture of the landscape is obtained.

There are two apertures in one side of the box, through one of these the picture is viewed, and through the other the hand may be thrust for the purpose of sketching it off.

The instrument is properly focussed by means of the sliding arrangement at the top. It is made of different sizes, and the sides are hinged to each other, so as to be folded up and placed

in the base of the instrument. In this way it can be conveniently transported from place to place.

2. *The Eye.*—Fig. 2 shows the structure of the eye. "The opaque coating *A*, known popularly as the 'white of the eye,' consists of tough fibrous tissue, and is called the *sclerotica.* The front part, *C*, is an extension of this coat, with the important difference, however, of being transparent, and is called the *cornea.* In the posterior chamber, in immediate contact with the sclerotica is the *choroides, B*, a delicate membrane of winding blood-vessels, covered over with a black velvety pigment,* obviously to prevent internal reflexion. Inside this again is the *retina G*, a very fine network of nerves; upon this as a curtain or screen the images of objects are focussed, and being an extension of the optic nerve *H*, which communicates with the brain, the impressions give rise to the sensation of vision. Behind the cornea is the *crystalline lens L*, having the form of a double convex lens of unequal curvature, highly elastic, and consisting of concentric layers of tissue which increase in consistency, and therefore in refractive power, towards the centre. It is held in its place by the *ciliary* membrane, which is acted upon by a series of muscles called the *ciliary muscles F. D* is the *iris*, a curtain or diaphragm in connection with the ciliary membrane, having a central opening called the *pupil M.* The iris is differently coloured in individuals, giving rise, therefore, to difference of colour in eyes. The iris performs the important function of regulating the quantity of light which passes into the interior chamber of the eye, by its enlarging or contracting the diameter of the pupil. When the eye is exposed to a great glare of light, the edges of the iris, which are in close contact with the lens, approach, and thus contract the pupil; when there is little light passing in, the pupil is expanded. The changes which the iris undergoes, however,

* It has been found, lately, by physiologists, that a coloured or dark pigment is also necessary for proper hearing and smell. When it is absent, as in perfectly white animals, these senses are defective.

require time; hence the impression produced when a person passes from a highly illuminated room into the open air at night; he imagines it darker than it really is—the fact is, he emerges with his pupil in a very contracted state, and it is not till after some time has elapsed that his pupil dilates sufficiently to allow him to form a more correct judgment. The anterior and posterior chambers of the eye are filled with fluid which are called respectively the *aqueous humour*, from its resemblance to water, and the *vitreous humour*, resembling more a delicate jelly than a regular fluid" (Lees' Acoustics, Light, and Heat).

3. *Distinct Vision.*—In order that we may see an object *distinctly*, it is necessary that the rays from it be brought to a focus on the retina (see fig. 2). To avoid complication in the diagram, the *crystalline lens* is represented as the chief agent towards the concentration of the rays. It must be understood, however, that in reality the other parts of the eye are concerned also in this function. The image of the object upon the retina is necessarily inverted, and must vary in size with the distance of the object.

"The eye possesses a wonderful power of accommodating itself to the distance at which an object may be placed. This accommodation is effected by the *movements* of the crystalline lens. The suspensory ligaments are such as to cause a slight movement of the lens either forwards or backwards, according to the distance of the object looked at, whilst at the same time, from its elasticity, the *curvature* of the lens is also slightly changed."

"How then, it may be asked, can we form so correct a judgment of the *size* of objects? The reason is that we learn by habit and experience to take into account the *distance* at which an object may be placed. A child, for instance, placed near us, may present the same size of image on the retina as a man at some distance off, yet we are in no way misled as to their real sizes; we do not imagine that the child is as tall as the man. We learn by experience to combine, in our judgment, the *dis-*

*tance* at which the child is in reference to the man; and thus it is that we are led to correct the impressions which our eyes, of themselves, would convey."

4. *Persistence of Impressions.*—"The impression which light makes on the eye is not obliterated *instantaneously;* it continues for a short time after the cause of that impression has ceased to act. Its duration is found to vary with different eyes, and also with the intensity and colour of the light; but, in all cases, its amount is a sensible fraction of a second. If, therefore, a series of distinct impressions be made upon the eye, which succeed each other with sufficient rapidity, these impressions will be blended together and will produce a continuous sensation. This persistence of impression explains the following familiar facts: the glowing end of a stick which has been thrust into the fire, when whirled rapidly round, gives the appearance of a continuous circle of light. A flash of lightning is seen for a time as an unbroken track of fire in the heavens. A falling star presents a similar appearance. So also, when it is raining heavy, there appear so many lines of water falling to the ground.

"On this principle a number of entertaining instruments have been constructed. The *magic disc*, the *thaumatrope*, the *kaleidophone*, the *wheel of life*, the *chromotrope top*, etc., all owe their action to this principle."

5. *Far-Sight.*—The two common defects of eyesight are *far-sightedness* and *short-sightedness.*

Fig. 3 shows the state of the eye in far-sight.

The crystalline lens falls off in its converging power, and is therefore incapable of bringing the rays from the object to a focus on the retina. An image of the object *A B* would be formed (were that possible) *behind* the retina at *A′ B′*. In reality, the rays fall upon the retina in a *scattered* state, and indistinct vision is the consequence.

This defect is common to elderly persons, and naturally increases with age. The remedy is to use *converging* lenses or

"spectacles" of just sufficient strength to enable the eyes to focus the image on the retina.

6. *Short-Sight.*—Fig. 4 shows what happens in short-sight.

The eye in this case has too much convergent power. An image of the object *A B* is formed at *A′ B′*, in *front* of the retina. The rays fall upon the retina, therefore, in a state of divergence, and indistinct vision is the consequence.

This defect is not uncommon in young persons, and in cases where it is decided, the eyeballs are observed to be prominent.

The remedy is to use *diverging* glasses of just sufficient strength, as before, to enable the eyes to bring the rays to a focus on the retina.

As a short-sighted person advances in life his eyes fall off in their converging power, hence it may happen that in old age he may be able to dispense with the use of spectacles altogether.

7. *Cause of Single Vision.*—"As there is an image of the object in each eye, it may be asked, why is it we do not see *double* when we use both eyes? This question is not difficult to answer. When we fix our eyes upon an object, each eye arranges itself in a particular manner. Thus, let *B C* be the two eyes (fig. 5), and *A* the object. Draw *Aa, Aa* through the centre of the crystalline lens, and at right angles to the convex surfaces. These lines are called the *optic axes*, and the angle between them, *aAa*, the *optical angle*. The eyes adjust themselves so that the optic axes intersect each other *at* the object. In consequence of this, a precisely similar image of the object is formed in each eye, and therefore a precisely similar impression of the object is conveyed to the mind. If either eye be prevented from thus adjusting itself by slight pressure on the eyeball, double vision results. Hence persons who *squint* have always double vision. It thus appears that single vision arises from the circumstance that the image is cast upon *corresponding* parts of the retina in both eyes.

"If, whilst the eyes are directed upon a small object at *A* (fig. 5), there is another object *A′* placed beyond, that latter object

will be seen double. This results from the images in the two eyes being thrown upon *different* parts of the retina. Thus, the image in $B$ is formed on the *left* of the optic axis, and that in $C$ on the *right*. If the eyes be directed upon $A'$, then $A$ will be seen double for the same reason.

"It is possible to have a double image with *one* eye. For this purpose, make two small holes with a pin in a card about $\frac{1}{8}$ of an inch apart; place the card close to one eye, and look through these holes at a round spot of ink on a piece of white paper, two spots are seen thus , the circles being the holes which appear to overlap. The one spot, however, is seen to be much fainter than the other."

8. *The Stereoscope.*—In looking at any object, the pictures formed upon the retina are not *identical* in both eyes. The view of the object presented to the right eye is not the same as that presented to the left eye.

It follows, therefore, that if we can obtain faithful pictures of the object as they are seen by the two eyes, and have a means of combining these pictures, an idea of *relief* or solidity will be conveyed to the mind. Photography enables us to obtain these pictures very perfectly, and the stereoscope aids us in obtaining a *simultaneous* impression of both.

The instrument is constructed as follows:—

A lens $L$ (a vertical section of which is represented in fig. 6 ($a$)) has its sides cut away ($b$), the remaining portion is then divided in the middle, and the two parts are turned over, and their edges set in juxtaposition, as shown in ($c$). The glasses are mounted on a sloping box, blackened inside, with a partition running down the centre.

The principle of its action will be understood from fig. 6 ($c$). Suppose $C$ and $C'$ to be the two pictures of an object. The rays of light proceeding from them, in traversing the glasses, are refracted and enter the eyes at $E$ and $E'$, as if they came from a single picture at $D$. Thus the pictures are seen blended together, and the impression conveyed to the mind of reality or relief.

9. *Stereoscopic Pictures.*—Fig. 7 shows the difference that may arise between the pictures of the same object, as cast upon the retina. The object, it will be seen, is a candle and candlestick. The pictures *A* and *B* are enlarged representations taken from a real stereoscopic slide.

10. *Newton's Experiment.*—Sir Isaac Newton was the first to unravel or decompose a beam of solar light. He admitted a sunbeam *S* into a darkened chamber (fig. 8), and interposed in its path a prism of glass *P*. He found depicted on the opposite wall an elongated image of the sun, and coloured with a variety of tints, the most prominent being red, orange, yellow, green, blue, indigo, and violet. To this image he gave the name of the "solar spectrum."

Allowing each of these colours to pass in succession through another prism, he found no farther decomposition. The red rays gave a red image merely, the yellow a yellow image, and so on. From this he concluded that sunlight consisted of these seven colours, and these only.

By this method the coloured spaces, with the exception of the red and violet, are not well defined. The elongated image, in fact, is made up of a series of spectra which run into or overlap each other, and thus in reality a great variety of tints is obtained.

In order to have a *pure* spectrum, that is, one in which this overlapping is avoided, the beam must be admitted through a very narrow slit, and sent through several prisms in succession, so as the more effectually to separate the colours; even then the mingling of colour is not wholly prevented.

11. *Entire Spectrum.*—The solar spectrum is proved by experiment to consist of *three* parts, nearly of equal length—the ultra-red, the luminous, and the ultra-violet space (fig. 9). The first and last spaces are, under ordinary circumstances, invisible. The three parts differ in character from each other. The ultra-red space is rich in *heat* rays; the luminous space in *luminous* rays; the violet and ultra-violet space in *chemical* rays, hence the value of this latter portion of the spectrum to

the photographer. The degree to which these different powers are exhibited is well indicated by the curves in the diagram. The extent to which the curves rise above the spectrum serves as an index to the different powers specified.

12. *Dark Lines in the Solar Spectrum.*—The spectrum is crossed by a great number of dark lines,* not at equal distances, but grouped together in considerable quantity, more in some places than in others. They are known as *Fraunhofer's lines,* from the circumstance that, that physicist was the first who carefully studied and mapped them out.

Fig. 10 shows some of these lines well; the *chief* lines are marked by the letters of the alphabet (fig. 9). In the spectra of the electric light, of gas and candle flames, they are absent.

13. *The Spectroscope.*—"This instrument has been devised for the purpose of analyzing the rays of light emanating from any luminous source. A convenient form of it is represented in fig. 11; it is the form known as the 'direct-vision spectroscope.' It consists of three tubes which can be screwed on to each other, and which, when the instrument is unused, can be packed into a suitable box. *S* is a vertical slit, the width of which can be regulated by the screw *D*. A narrow pencil of light being thus admitted, falls upon the lens *L*, so adjusted as to have the slit in its principal focus. The parallel emergent beam then passes through a series of prisms in the central tube *AB*, and undergoes dispersion. The prisms *F*, *F* are constructed of flint-glass, *c*, *c*, *c* of crown-glass, an arrangement which causes a minimum of deviation in the dispersed beam. The spectrum thus formed is viewed by the telescopic tube *BE*, which has a compound eyeglass, capable of being moved out for the purpose of focal adjustment. The instrument can be fixed in a stand, and thus the spectra, from different sources of light, can be carefully examined."

14. *Different Spectra.*—One of the most interesting results obtained by the spectroscope is this: *that glowing vapours and*

* As many as 2000 have been counted.

*gases give out spectra with bright lines on a dark background, and these lines are different for different substances.*

Fig. 12 represents some specimens. (1) Is the spectrum of *sodium* vapour; (2) of *caesium;* (3) of *strontium;* and (4) of *barium.*

15. *Spectrum Analysis.*—"This method consists in revealing the chemical elements or constituents of a body by the character of its spectrum when reduced to a state of glowing vapour. Each substance, as stated above, has its characteristic line, or group of lines. Even if the substance be compound in its nature, each constituent will invariably reveal its own peculiar line or lines, so that the resulting spectrum requires only to be minutely examined, in order that its elements may be individualized.

"Having made ourselves acquainted, therefore, with the spectra of all the known chemical elements, should any new line or lines be revealed in the examination of a substance, there is positive evidence afforded that some new element is present. In this way it was that Bunsen and Kirchhoff, the founders of the method, discovered two new metals, 'caesium' and 'rubidium,' which had previously been unknown to chemists; and, subsequently, other investigators added 'thallium' and 'indium' to the list."

16. *The Rainbow.*—"This phenomenon is caused by drops of rain acting like prisms in decomposing the solar beams. It is witnessed, as is well known, only when the sun is within a certain altitude above the horizon, and when rain is falling *between* the observer and the part of the sky opposite to the sun.

"It may also be observed in the spray of waterfalls, and often as a complete circle of coloured light when the position of the sun is favourable.

"It is not difficult of explanation: The solar rays which fall near the top of the drops are refracted, and such of them as are incident at the back, within the *limiting angle,* are totally reflected. On emerging, the rays are decomposed into their constituent colours, most of which proceeding in a state of

divergence do not affect the eye. At *certain* angles, however, the emergent coloured rays proceed in parallel directions, and therefore become visible. Let *A* and *B* (fig. 13) represent two raindrops, *S*, *S*, the solar rays. On emerging from the drops the rays are decomposed, and such of them as emerge in *parallel* directions affect the eye. The rays from the drop *A* being red rays, and those from *B* being violet rays, these meet at some point *O*, enter the eye there, and produce their respective impressions. The drops between these in like manner transmit the intermediate colours, and thus a perception of the seven colours is conveyed to the eye.

"To understand the *bow-shape*, conceive a line *SC* drawn from the sun through the eye of the observer, and produced to the sky. Further, conceive a line drawn from the eye, making an angle of 42° 30′ with the former line, and moving round it—this line will pass through *all* the drops which are capable of transmitting parallel beams of red light, and hence an *arc* of red light will be seen *uppermost*. In like manner, if another line be conceived drawn from the observer's eye at an angle of 40° 30′ with the first line, and move round it, this one will strike the drops which transmit the violet light. The angles at which the other colours are transmitted are intermediate to these limits, and hence a band of light, coloured with the several tints of the spectrum, is seen projected on the opposite sky. The extent of the arch depends upon the sun's altitude; it is greatest when the *sun is in the horizon*. In this case, the observer, if situated on a high mountain, may see almost a complete circle.

"The bow, just explained, is called the *primary* bow, to distinguish it from another which is seen to accompany it when the sun is sufficiently low in the sky, and which is called the *secondary* bow. This results from the solar rays, which enter near the *bottom* of the drops. They undergo two refractions and two reflexions (fig. 13) in passing through the drops. The secondary bow is above the other, and has the *violet* band

uppermost; it is also fainter, in consequence of the greater loss of light by the two reflexions."

17. *Interference of Light.*—Two rays of homogeneous light, meeting at a point, may, under certain circumstances, produce *darkness*. How this is possible will be understood from fig. 14.

Let $A$ and $B$ ($a$) be two sets of ethereal waves proceeding towards the point $O$. It is clear that if the undulations of the one system correspond with those of the other, in other words, if the two wave systems are in the *same* phase of vibration, then their junction at $O$ will cause an increase in the *motion* of the particle of ether there, and therefore that the intensity of light will also be increased. But now let the wave systems $A'$, $B'$ ($b$) be in *opposite* phase of vibration, then when they meet at $O'$, the particle of ether, there, will be as much influenced in the one direction as in the opposite direction, and it will therefore remain at rest. A destruction of light at $O'$ will be the consequence.

This remarkable phenomenon is known as the "interference" of light.

This may be regarded as the *experimentum crucis* of the "undulatory" theory of light.

18. *Newton's Rings.*—To produce what are known as Newton's rings take a piece of a plane glass and place upon it a plano-convex lens (convex side underneath) of very small curvature. On exposing the apparatus to the sun's rays, a series of coloured rings are obtained, which are observed to decrease in breadth from the point of contact (where there is a dark spot), and at the same time to get closer and less distinct.

The phenomenon is due to "interference." The colours of the soap-bubble, of oil on the surface of water, of lead-scum, of mother-of-pearl, are due to the same cause.

If the apparatus be taken into a dark room and viewed by the reflexion of homogeneous light, such as that of a spirit-lamp with a salted wick, there is seen at the point of contact a black spot, encircled with a series of alternately yellow and dark rings.

Fig. 15 shows these "rings."

19. *Simple Microscope.*—Fig. 16 shows the action of a common magnifying glass.

The object *A B* must be placed between the principal focus *F* and the lens. The rays proceeding from it, in passing through the glass, are refracted, and enter the eye as if they came from a real object at *A' B'*. Thus there is obtained a *magnified* image (erect) of the object.

20. *Compound Microscope.*—"A *compound* microscope consists essentially of two glasses, the one next the object is called the *object* glass, or *objective*, the other the *eye*-glass, or *ocular*. Its action will be understood from fig. 17. The small object *ab* being placed a little beyond the principal focus *F* of the objective *C*, an inverted enlarged image of it is formed at *AB* in the conjugate focus. If, now, the ocular *D* be so adjusted as to have this image between *its* principal focus *F'* and itself, the image *AB* will be further magnified to *A'B'*. Thus the object *ab* is *twice* magnified. The objective has a much shorter focal distance than the ocular, and in order to adjust the instrument to objects of varying size, the objective is fixed in a tube which is capable of sliding up or down inside that containing the ocular. In the best instruments, objectives of different power are provided, fixed in small tubes, which can be screwed on to the end of the sliding tube according to the strength desired. In this way the magnifying power of the instrument may vary from 30 to 500, or even beyond. The eye-piece is usually formed of several glasses, for the purpose of securing greater distinctness in the image, but their combined action is the same in principle as that of a single ocular, such as has been described. The glasses are all made 'achromatic.' Sometimes two tubes are used, adapted to the two eyes, and made to converge upon the single tube containing the objective. This is a convenient arrangement for physiologists and others who are much engaged in investigation."

21. *Astronomical Telescope (Reflecting).*—There are two kinds of telescopes, the *reflecting* and *refracting.*

Fig. 18 exhibits the construction of the "Gregorian" reflecting telescope.

The reflector $R$ has a circular aperture in the centre, opposite which are fixed the eye-tube on the one side, and at some distance on the other a small concave reflector $n$.

The principle of action is as follows: An inverted image is formed of the remote object by the reflector $R$ at $ab$; the rays thereafter crossing each other fall upon the small reflector $n$, and are concentrated a second time, with the aid of a lens at $a' b'$; that image having now the same position as the original object, is magnified by the ocular. The small reflector $n$ is made fast to a rod which runs along the side of the tube and by which the focal adjustment is effected.

The most remarkable reflecting telescopes constructed are the "Herschelian" and "Lord Rosse's." They consist of long tubes open at one end and closed at the other. At the closed end there is placed a concave reflector inclined at a small angle to the side of the tube. The image of the distant object is formed at the *side* of the open end, and is magnified by an appropriate eye-piece.

In the former, the tube is 40 feet long, and the reflector has a diameter of 4 feet 2 inches; in the latter, it is 54 feet long, with a reflector of 7 feet in diameter.

These large instruments have led to some very important discoveries in astronomy.

22. *Refracting Telescope.*—Fig. 19 exhibits the construction of the refracting telescope.

"The distant object $AB$ has an inverted image, formed by the objective at $A'B'$, somewhat beyond the principal focus $F$. This image is magnified by the ocular in the same manner as before, and thus the distant object appears to have the size $A''B''$. It is the case that $A''B''$ is really smaller than $AB$, but owing to its nearness to the eye, as contrasted with the distance

of the object, in other words, to the difference in the size of the 'visual angle,' the remote object appears magnified. The magnifying power will evidently depend upon the size of the image *A'B'*—the greater the distance from the objective, or which is the same thing, the greater the focal length of the objective, the larger this image. Hence in a powerful telescope of this kind the objective used must have a long focal distance, which, of course, implies a tube of considerable length. For the purpose of adjustment, the tube containing the eye-piece slides into the other. In order to have the image bright and distinct, a large objective is required; in the telescopes used in observatories, it is not unfrequent to have objectives 16 inches in diameter, with a focal length of about 24 feet. A few years ago a large instrument was constructed at York; it is 32 feet long, and has an objective of 2 feet 1 inch in diameter."

23. *The Terrestrial Telescope.*—"The image of an object, as seen in an astronomical telescope, is evidently *inverted*. This, of course, is no drawback in viewing a celestial body; but in a telescope adapted for terrestrial objects, it is desirable to have this inversion corrected. Accordingly this is done in the *terrestrial* telescope. It is usually effected by introducing two additional glasses *C*, *D*, of the same strength (fig. 20), into the tube containing the ocular. The action of the instrument is as follows: An image of the object *AB* is formed at *ab* in the conjugate focus, inverted. This image being placed in the principal focus of the lens *C*, the rays, after emergence, pass in parallel directions, and cross each other at the aperture of a diaphragm *d*, interposed to arrest stray light; they then fall upon the lens *D*, and on emerging from this, form an erect image *a'b'* in its principal focus. Lastly, this image is magnified by the ocular in the same manner as before. To adjust the instrument for objects at different distances, the compound ocular is placed in one tube, and the objective in another. Sometimes a middle tube is introduced—all sliding into each other, to focus the instrument more perfectly."

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# JOHNSTON'S

# ILLUSTRATIONS OF LIGHT AND HEAT.

## *HEAT* (*Part I.*)

*N.B.*—The numbers of the paragraphs do not correspond with the numbers of the diagrams.

1. *Nature of Heat.*—Heat is believed to be due to a vibratory motion going on, in the particles of a body. The warmer the body, the more rapid is that motion.

Further, it is supposed that heated bodies are capable of communicating a vibratory motion to the surrounding *ether*, in virtue of which contiguous bodies also become heated. The hotter a body is, therefore, the more it excites the ether, and the greater its effect on adjacent bodies.

2. *Heat and Cold.*—These are popularly recognised as separate influences. The physicist does not view them as such; they are merely different degrees of the same influence, viz. *heat.*

Bodies (with very few exceptions) expand on receiving an increase of heat, and contract on losing heat. This principle, according to ordinary *parlance*, may be stated thus: *Heat expands and cold contracts.*

3. *Linear Expansion.*—Two kinds of expansion are distinguished—*linear* and *cubical.* The former has reference to expansion in length, and the latter to expansion in volume.

Fig. 1 exhibits an apparatus to illustrate linear expansion. A metallic bar *A* is supported as in the figure. One end fit into a socket, whilst the *free* end is made to act on the leve

*B C*, which in turn affects the index lever *D*. By this arrangement a multiplying effect is produced, and the index records, by its movement up the graduated arc, the smallest elongation on the part of the bar.

4. "*Fracture by Contraction.*—The force with which a solid expands or contracts by the addition or abstraction of heat is almost irresistible. Fig. 2 exhibits an apparatus by which the force of contraction is well illustrated. It consists of a strong iron frame. *A* and *B* are two uprights, having sockets for the reception of an iron bar. At the end *C* there is an aperture through which a small rod of cast-iron slides, and at the other end a bolt *D* working in a screw. The bar is first heated to redness, and placed as in the figure; the small cast-iron rod is then introduced into the aperture, the bolt screwed up tightly against the support *A*, thereby bringing the extremities of the rod hard up upon the edged mountings of the support *B*. In a few minutes the bar falls in temperature, and contracts sufficiently to break the little cylinder. The fracture is accompanied with considerable noise, and very generally the iron bar starts out of its sockets altogether.

5. "*Practical Applications.*—The principle of expansion or contraction is utilized much in practice. The hoop of iron by which a wheel is surrounded is made of the same diameter as the wheel. It is then heated, and in this state is put on the wheel. The whole being thrown into water, the iron hoop contracts with great force, and thus binds the spokes and rim firmly together. A similar method is employed for binding together the staves of tubs, vats, barrels, etc. The walls of a building have been restored to their perpendicular position by taking advantage of the enormous contractile force of iron.

"In the combination of metallic pipes, by which water is brought from great distances for the supply of towns, means must be provided for allowing expansion or contraction to take place freely. Hence the pipes are so constructed as to be capable of sliding one within the other, after the manner of the joints of a

telescope. In iron bridges similar precautions are necessary; they are generally supported on friction rollers.

"The same principle explains certain familiar facts. Thus, when hot water is poured into a cold glass vessel, fracture often takes place. This arises from the *unequal* expansion of the glass, the heat not having had sufficient time to extend its influence equally to other parts of the vessel. The same accident may take place when cold water is poured into a warm glass vessel. When the stopper of a decanter becomes firmly fixed, it is not unusual to wrap a cloth steeped in hot water round the neck; the neck thereby expands, and the stopper is freed from its hold."

6. "*Compensation Pendulums.*—In the finer kinds of clocks the variation of temperature is guarded against by the use of what is called a *compensation* pendulum. A common form is the 'gridiron' pendulum, represented in fig. 3. It consists of a combination of steel and brass rods, *A*, ranged alternately, and of such length as that the expansion or contraction of the steel rods may be exactly neutralized by the expansion or contraction of the brass ones. To the end is attached the bob *B*. To illustrate its action, let *C* be the *centre of oscillation* of the pendulum, that is, let the distance between the axis of suspension and the point *C* be the length of the equivalent *simple** pendulum. In summer the steel rods will expand, and thus tend to lower the point *C*, or lengthen the pendulum; but the brass rods also expand, and, by their so doing, they tend to raise the point *C*, or shorten the pendulum. If, therefore, the point *C* is as much raised by the expansion of the brass rods as it is depressed by the expansion of the steel ones, it will be kept in the same position; in other words, the length of the pendulum (proper) will be unchanged. In winter, in like manner, if the effects of contraction in the one case be equal to the effects of contraction in

* By a *simple* pendulum is meant a heavy particle attached to the end of a perfectly flexible thread. Such a pendulum would oscillate in the same time as the one in question.

the other, the length of the pendulum will be preserved. Hence, by this arrangement, the pendulum is kept constant in its length.

"Another form is the 'mercurial pendulum' (fig. 4). It consists of a steel rod connected with a metallic cylinder, which is filled to a certain level with *mercury*, hence the name. Its action is as follows: On an increase of temperature the rod* *A* expands, which would thus lower the centre of oscillation in the bob *B*; the mercury also expands, but in an upward direction, thereby raising the centre of oscillation. If, therefore, as before, that point is as much raised by the expansion of the mercury as it is depressed by the expansion of the rod, it will be kept in the same position; in other words, the *length* of the pendulum will be kept unaltered. The opposite effect takes place with a decrease of temperature.

"The important matter in a pendulum of this description is the proper quantity of mercury to be put into the cup. This is usually effected by experiment. If, for example, it should be found, when the temperature rises, that the clock goes too slow, it indicates that the centre of oscillation is more *depressed* by the expansion of the steel rod than it is raised by the expansion of the mercury. There is, therefore, too little compensatory power; in other words, *more* mercury must be put in, and thus by a series of trials just that quantity is obtained which exactly neutralizes the changes of length which the rod may undergo."

7. "*Compensation Balance-Wheel.*—The principle of compensation is also applied in the finer kinds of watches, and also in chronometers. A common form is represented in fig. 5 (*a*). The rim is a compound strip of brass and steel (brass outermost), and consists of two half circles *A'B'*, *C'D'* attached to the ends of the spoke of the wheel, the points of separation *C'* and *B'* of the rim being thus at opposite ends and sides of the spoke. On the half circles are disposed several small brass screws for the purpose of *timing* the wheel. When the temperature rises, the

* The rod *A* works through the top of the cylinder by a screw. The index shown in the diagram is for the purpose of adjustment.

steel spoke expands; the half rims thus recede from the axis, but these become more *curved* than before, and in consequence the small weights are made to approach the axis. If, therefore, the *centre of oscillation* of the wheel is as much moved in by the increased curvature of the rim as it is moved out by the expansion of the spoke, it is clear that it will be kept at the same distance from the axis, and the elasticity of the hair-spring will have the *same* amount of resistance to overcome. When the temperature falls, the *curvature* of the half rims is lessened, and the opposite effects ensue." *

Fig. 5 (*b*) represents another form of the compensation balance-wheel. The principle of its action is the same.

8. *Expansion of a Liquid.*—Fig. 6 exhibits an apparatus for demonstrating the expansion of a liquid, such as water. A tube *A B* with a bulb at the end is taken and filled to a certain height with coloured water. It is placed in a stand *S*, and a lamp is applied to the bulb. As the heat passes in, the water is observed to rise in the tube, and pretty rapidly, owing to the large capacity of the bulb in reference to the tube.

No liquids have been more thoroughly examined, as regards their expansibility, than alcohol, water, and mercury; of these, alcohol is the most expansible. Alcohol and mercury are the two liquids that are universally used for thermometric purposes. Alcohol is used in the *minimum* thermometer, as it is found to resist congelation under the greatest known cold, and mercury in the ordinary thermometer. The latter fluid, from the fact of its being uniformly expansible under a considerable range of temperature, is found well adapted for this purpose.

9. *The Thermometer.*—The ordinary thermometer (Fahrenheit's), as used in this country, is represented in fig. 7 (*a*). It consists of a closed tube of *uniform* bore, terminated with a bulb, either spherical or cylindrical. Attached to the tube is a scale graduated as follows: The bulb and tube being previously prepared and filled with mercury, the bulb is plunged into

* Lees' Advanced Acoustics, Light, and Heat.

*freezing* water, the mercury sinks in the tube to a certain level, which is marked on the accompanying scale 32°. It is then plunged into boiling water (barometer about 30 inches), the mercury rises and at length settles at a particular level; that level is marked 212°. The interval between these points, viz. 32° and 212°, is then divided into 180 equal parts. The same equal graduation is carried down below 32° to 0°. If the graduation be carried below 0°, the temperature is indicated by a negative; thus − 5° indicates 5° below the zero point.

10. *Thermometric Scales.*—There are three modes of graduation adopted in thermometers. In Fahrenheit's thermometer, as has been explained, the freezing point is marked 32°, and the boiling point 212°. In the Celsius or centigrade thermometer (much used on the Continent) *these points* are respectively marked 0° and 100°, whilst in Reaumur's thermometer (used in Russia and elsewhere) they are marked 0° and 80°.

Fig. 7 (*b*) shows these graduations.

11. *Conversion from one Scale to another.*—The means of conversion from one scale to another will be understood from what precedes.

The *same* interval which in Fahrenheit's thermometer is divided into 180 equal parts is divided, as we have seen, into 100 equal parts in the centigrade, and into 80 in Reaumur's thermometer; that is, the proportion in the three scales is as 180 : 100 : 80, or as 9 : 5 : 4.

A few examples will illustrate the process.

Example I. Convert 62° F. into the centigrade scale.

Here we must begin by subtracting 32 from 62, owing to the difference of graduation of the freezing point in the two scales. 62 − 32 = 30. We have then to state by ordinary proportion as follows:—

$$9 : 30 :: 5 = 16\tfrac{2}{3}°. \quad \textit{Ans.}$$

Example II. Convert 10° C. into F.

Here we have to state thus: $5 : 10 : 9 = 18°$.

But, as before, making allowance for the difference of graduation, we must add 32°; hence, 10° C. = 18° + 32° = 50° F. *Ans.*

EXAMPLE III. Convert $-15°$ C. into F.

Keeping in the sign, we have $5 : -15 :: 9 = -27$.

Adding 32, we have $32 - 27 = 5$;

hence, $-15°$ C. $= 5°$ F. *Ans.*

EXAMPLE IV. Convert 20° C. into R.

Here we have to state thus: $5 : 20 :: 4 = 16°$.

As the freezing point in the two scales is marked similarly, we have therefore 20° C. = 16° R. *Ans.*

It is to be remarked that in the conversion from the Fahrenheit scale into either of the other scales, 32 must be deducted *first* before stating the proportion; and conversely from either scale into Fahrenheit, the 32 must be added *after* the proportion is worked.

A good deal of confusion sometimes arises from the ordinary way of speaking of temperature in frosty weather. Thus it is common to speak of 10° or 15° of frost, meaning that the thermometer is down to 22° or 17°. The *real* indication of the thermometer is the more scientific way of stating the temperature, and would tend to obviate any dubiety.

12. *Maximum and Minimum Thermometers.*—These are for special purposes. The first is designed to record the highest temperature that has been attained through the day. It is represented in fig. 8 (*A*). In front of the mercurial column is set a small cylinder of lead *L*. The instrument being hung in a horizontal position, and the small cylinder made to touch the mercury, as the temperature rises, the mercury moves along the tube and pushes the cylinder before it till the highest temperature has been reached, when the mercury retires and leaves the cylinder isolated. The point in the scale at which the end of the cylinder *next* the mercury stands marks off the maximum temperature.

The minimum thermometer, represented in fig. 7 (*B*), is designed to indicate the lowest temperature that has taken place through the night. There floats in the coloured alcohol a small cylinder of glass *G*. The instrument being also adjusted horizontally and the glass cylinder moved to the end

of the spirit column, as the temperature falls the alcohol and cylinder retire towards the bulb till the *lowest* temperature has been reached, when the alcohol returns and leaves the cylinder in the position it had at the lowest temperature. The end of the little cylinder *remote* from the bulb indicates the minimum temperature. This instrument is largely used amongst farmers and horticulturists.

13. "*Boiling of a Liquid.*—The process by which water is raised to the boiling point is a very interesting one. Thus, let an open flask of water be exposed to heat, as in fig. 9. The stratum of fluid at the bottom, in becoming heated, expands and rises to the surface; another stratum taking its place, in like manner expands and rises, and so on successively. There are produced, therefore, in the vessel a series of ascending warm currents and of descending colder currents, and this circulation continues until the water is nearly brought to the boiling point. When this point is reached, bubbles of gas are observed to form themselves next the heating source. These at first, in their passage upwards through the colder water above, are gradually condensed, and diminishing in volume as they ascend scarcely reach the surface; but in proportion as the *whole* water approaches the boiling point this condensation ceases, and the bubbles escape at the surface as steam. The water is then said to *boil*.

14. "*The Dependence of the Boiling Point upon External Pressure.*—The temperature at which water boils in an open vessel is dependent upon the pressure of the atmosphere. At the ordinary pressure, that is, when the barometer indicates about 30 inches of mercury, the boiling point is 212° F. If the pressure diminish, the boiling point falls; on the other hand, if the pressure increase, it rises above the temperature of 212°. Hence the necessity of strictly defining what the *boiling point* of a liquid really is. It is *that point of temperature at which the tension or elastic force of its vapour is exactly equal to the pressure it supports.*

"The variation of the boiling point of water with the pressure will be seen from the following table:—

| Height of the Barometer. (Inches.) | Boiling Point. (Fahrenheit.) |
|---|---|
| 17·04 | 185° |
| 18·99 | 190° |
| 21·12 | 195° |
| 23·45 | 200° |
| 25·99 | 205° |
| 28·74 | 210° |
| 29·33 | 211° |
| 29·92 | 212° |
| 30·51 | 213° |
| 31·73 | 215° |

"From this table it appears that a variation of $\frac{1}{10}$ of an inch of the barometer causes a difference of about $\frac{1}{6}$ of a degree Fahrenheit in the boiling point; hence the range of the boiling point in our climate may be as much as 5°, with the ordinary variations of the barometer.

"In a *closed* vessel, water may be raised to a much higher temperature than 212°. This is the case in the boiler of a steam-engine, or of a locomotive. By the accumulation of the steam the pressure on the water is increased, the boiling point is therefore raised, or the water is heated above its ordinary boiling point. Under a pressure of *two* atmospheres, water is found to boil at a temperature of about 249° F.

15. "*Illustrations.*—A striking illustration of the dependence of the boiling point upon external pressure is to take a vessel of hot water, put it under the receiver of the air-pump, and exhaust the air. In a short time the water begins to boil, and as the rarefaction goes on, the ebullition increases in intensity.

"Another experiment consists in taking a vessel of hot water *A* (fig. 10), corking it up, and then inverting it. If now cold water be allowed to fall over the confined vapour, it partially condenses it; the water in the vessel, therefore, is so far relieved from pressure, and in consequence enters into a state of ebullition."

16. "*Maximum Density of Water.*—If a quantity of water, say at the temperature of 62° F. (standard temp.), be gradually

cooled down, it contracts until it reaches the temperature of 39·4°, when all further contraction ceases. This point is called the point of *maximum density*. When cooled below this temperature, *expansion* sets in, which increases rapidly as the freezing point is approached. Water is therefore *heaviest* at the temperature of 39·4° F. or 4° C. For example, a cubic foot of water at this temperature weighs more than a cubic foot at any other temperature.

17. "*Deportment of Water in Freezing.*—When water freezes, it undergoes a sudden expansion. The amount of its expansion is found to be about 10 per cent.; more exactly, 1000 cubic feet of water at the freezing point become 1102 cubic feet of ice at the same temperature.

"The force of this expansion is almost irresistible. A strong iron bottle filled with water, and firmly closed, when immersed in a freezing mixture, is rent asunder in a short time. Some interesting experiments on this point were made one severe winter at Quebec by Major Williams. He took a bombshell, and having filled it with water, carefully plugged up the aperture; on exposing it to the frost, the plug was driven to a distance of 330 feet, whilst at the same time a cylinder of ice 8½ inches long appeared protruding at the aperture. In another experiment, the plug being more firmly fixed, the bomb was ruptured at the middle, and a ring of ice was forced through the rent.

"The common accident of the bursting of pipes in frosty weather can therefore be easily understood. The rupture takes place, of course, during the frost; but the rent being closed up with ice no leakage of water takes place. It is only when the thaw sets in that the damage done to the pipe becomes apparent.

"We can understand also what takes place when a lake is being frozen over. Suppose the average temperature of the water to be 45° F., and that frost suddenly sets in, the layer next the cool atmosphere contracts, and thus increasing in density sinks to the bottom; it is succeeded by another layer, which in turn being chilled, becomes heavier and sinks. The

same thing is repeated with layer after layer until the whole water is brought to a temperature of 39·4°, at which point the transfer of the liquid particles will cease. After this, expansion begins at the superficial layer, which goes on at an increasing rate till the freezing point is reached, when crystallization commences, and ice is formed. As the frost continues, the ice increases in thickness, because of its chilling power on the contiguous layers, and its conductivity of the cool temperature outside. During a severe frost, it often happens that the ice is rent in several places with long cracks; this is due to the contraction which has taken place on the part of the ice, resulting from the low temperature.

"Water, though the most familiar instance of a body expanding on solidification, does not stand *unique.* We have an instance of the same thing in bismuth. Thus if a metallic bottle be filled with molten bismuth, and firmly plugged up, the bottle is ruptured when the metal solidifies.

18. "*Effects in Nature.*—In the economy of nature the expansion which accompanies the freezing of water exerts a most important agency. Had water, in cooling, observed the general law of contraction, then a layer of ice when formed on the surface of our lakes or rivers would have sunk to the bottom; another would have been formed, and in like manner have sunk to the bottom, and so on until the whole water had become one solid mass of ice, which all the influence of a summer sun could scarcely have dissolved. As it is, however, these effects are happily prevented. The ice being lighter than the water floats on the surface, and thus the water below, being sheltered from the cold atmosphere above, preserves its liquid form.

"It is thus also that our soils are pulverized during winter. The water they imbibe, upon freezing, disintegrates them, and thereby assists, in no small degree, the labours of the husbandman in preparing them for the reception of the seed. Hence, during frost, the soil is observed to have a cracked appearance."*

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19. *Ice Crystallization.*—"A block of ice may seem of no more interest and beauty than a block of glass, but in reality it bears the same relation to glass that an oratorio of Handel does to the cries of a market-place. The ice is music, the glass is noise; the ice is order, the glass is confusion. In the glass, molecular forces constitute an inextricably entangled skein; in the ice they are woven to a symmetric web." *

Fig. 11 exhibits the wonderful structure of a slab of ice when the electric beam is made to pass through it. The heat of the beam breaks up the icy particles, and a series of stars and flowers are seen gradually to develop themselves. We can imagine the reverse process when a piece of ice is being formed out of watery particles.

20. *Expansion of Air.*—When a flask of water, as in fig. 9, is at first heated, bubbles of air are seen to rise through the water; this is owing to the expansion of the air-particles which have been absorbed by the water.

Fig. 12 shows an arrangement for illustrating, more strikingly, the expansion of air.

A flask *A* containing air is taken, from which a bent tube is led to a dish *B* filled with coloured water. Over the end of this tube is placed an upright tube *C*, previously filled with the fluid and inverted. If now the flask be heated, the air inside expands, passes through the bent tube, and gradually displaces the water in the vertical tube.

A method, similar to this, is adopted by chemists for the collection of gas in vessels.

21. *Draft of Chimneys.*—"When a fire is kindled in a room, the flame and warm smoke proceeding from it soon raise the temperature of the air in the chimney. The consequence is it ascends, and the colder air from the room flows in to supply its place; this air, in turn, likewise becoming heated, rises, and a fresh accession of air takes place, and so on.

"What constitutes, therefore, the *draft* of a chimney is nothing

* Tyndall on "Heat a Mode of Motion," p. 109.

else than the colder air of the room constantly passing towards the fireplace.

"As the air in a room is continually passing towards the fire, there must of course be a constant supply kept up from the external air, which must therefore have sufficiently free access by the doors and windows of the house. Hence it is found that in a house where the passage of the external air is much interrupted, the chimneys are liable to smoke, the reason being that a sufficient draft is not maintained.

"At the door of a room where there is a fire there are two opposite currents of air, the heated air in the room ascends to the top and passes out at the upper end of the door, whilst the colder air from without enters by the lower part. This may be easily proved by placing a lighted taper in these positions at the outside of the room door. In the former position the flame is bent *from* the door, and in the latter *towards* it.

"When all the windows and doors of a house fit so closely as to impede a communication with the external air, and thus prevent a sufficient supply for the fires in the house, the necessary quantity descends by those chimneys which are not in use. Hence, when a fire is being lighted in any of these, the smoke at first is driven into the room. To remedy this the room door ought to be shut, or the window opened; this being done, the chimney will soon begin to *draw.* What is called *back smoke* in a room where there is no fire arises from the circumstance that the chimney is serving as an inlet for air to supply the fires in the house, carrying the smoke of a neighbouring chimney down into the room along with it."

22. *Ventilation.*—"The grand object in *ventilation* is to allow the heated air, or air vitiated by respiration, to escape at the roof of the building, whilst provision is made at the same time for an inlet of fresh air, the whole arrangements being such as to obviate drafts. The principle of ventilation is strikingly illustrated by the following simple experiment: A glass receiver *R* (fig. 13), with an aperture at the top, is placed over a candle *C*

put into a flat dish *D*, in which there is water. In a short time the air in the receiver becomes vitiated by the combustion, and the candle flame, gradually dwindling down, is at last extinguished. If, however, the candle be relit, and a card be placed in the funnel, or chimney, thus dividing it into two parts, the candle continues to burn, preserving its brightness almost unimpaired. The reason of this is, that the vitiated air now escapes through one of the passages, whilst fresh air gets in by the other, as indicated by the arrows." *

23. *Winds.*—The phenomena of winds, in general, result from the unequal distribution of heat over the earth's surface.

"Fig. 14 gives a general view of the character of the winds which prevail in the northern hemisphere, from the equator to the pole. The arrows show the direction of the aërial currents. The warm air from the tropics, ascending to a certain height in the atmosphere, flows northward as an upper current; on cooling down it descends about the 30th parallel of latitude, and blows as a south-west wind between that parallel and the 60th; getting warm by contact with the earth's surface, it again ascends, still flowing towards the pole, where it at length precipitates itself and forms the Polar gales. Returning now southwards, it ascends at the 60th parallel, blowing as an upper current, till, on getting chilled, it descends at the 30th parallel, and, between that and the equator, blows as a north-east wind. Thus a continuous circulation of air goes on.

"It must be understood, however, that these aërial currents are subject to considerable variation, swayed as they are by a number of disturbing influences which more or less affect them."

24. "*The Hygrometer.*—This instrument, as its name implies, is intended to indicate or measure the quantity of aqueous vapour in the atmosphere. There are several forms of it. One in very general use is represented in fig. 15. It is known as the 'wet and dry bulb' arrangement. Two thermometers, *A B*,

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*C D*, graduated alike, are attached to a support. The bulb of the one is kept free, whilst that of the other is covered with thin muslin, from which trail a few threads of lamp cotton; these are led into a small cup *E* (supported by a wire *W*) containing water, and by capillary action keep the muslin always moist. Owing to evaporation from the wet bulb, and the consequent abstraction of heat from the mercury, the right-hand thermometer shows a *lower* temperature than the other; the greater the evaporation, in other words, the farther removed the air is from its point of saturation, the greater the difference between the readings of the two thermometers. If, therefore, this difference be considerable, it indicates that there is a small quantity of aqueous vapour; on the other hand, if the difference is small, that there is comparatively a large quantity.

"This instrument may, so far, also serve the purpose of a barometer. If the difference between the readings be observed to increase, for example, it affords an indication of fine weather; but if this difference decrease, rain may be anticipated.

25. "*Air Heated by Compression and Chilled by Expansion.*—When air is compressed heat is evolved. This can be shown by taking a brass cylinder *C* with a piston *P* fitting it air-tight (fig. 16). In a small aperture at the end of the piston-rod is inserted a piece of tinder *T*. If now the piston be forced down into the cylinder, the air inside becomes compressed, and sufficient heat is evolved to kindle the tinder.

"An instrument of this kind has been long in use among some of the native tribes of India.

"Again, when air is rarefied or expanded, cold is produced. A striking proof of this is afforded when a receiver is being exhausted by an air-pump. After one or two strokes a *cloudy* appearance is observed in the receiver, resulting from the condensation of the suspended vapour in consequence of the air being chilled.

26. "*Clouds—Rain.*—If a heated mass of air, charged with aqueous vapour, be carried aloft, it will expand by reason of

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"After a continuance of fine weather, it may have been often observed that though clouds are floating in the sky, and give promise of refreshing rain to the thirsty ground, there is no downfall for several days. The fact is, that rain is actually falling in the upper regions, but in consequence of the air below the clouds being non-saturated, the watery vesicles are evaporated in reaching this region; and it is only after the saturation of this air has taken place, that the vesicles unite in such quantity as to reach the surface of the earth as rain-drops.

27. "*Rainfall—Rain-gauge.*—The amount of rain which falls in any district in the course of a year is reckoned by the *number of inches* to which the ground would be covered, supposing the ground perfectly level, and the water neither to sink into the soil nor evaporate. The *rainfall* is measured by an instrument called "a rain-gauge." There are several forms of it. A common form is represented in fig. 17. A copper cylinder *A B* of 5 inches diameter is mounted with a cover having a conical inlet *C*, terminated by a tube which passes into a glass bottle *D* contained inside. This is accompanied by a glass vessel *V* of $1\frac{1}{2}$ inch diameter, and 12 inches in height, graduated so as to indicate $\frac{1}{100}$ of an inch of rainfall. After a fall of rain, the bottle is taken out, and the contents are measured by the graduated vessel. The instrument is examined from time to time, and a record is kept of the different quantities obtained in the course of a year. The *mean* annual rainfall of any place, which is usually regarded as the normal fall, is obtained by extending the observations over a series of years. The instrument is generally sunk a little in the ground, so that the top may be at least 6 inches from the surface, and quite horizontal. It is found that a rain-gauge *near* the surface of the ground always collects more water than when placed in an elevated position. The cause of this is not altogether understood. It seems to be due partly to the increase in size of the drops from the condensation of the vapour as they fall towards the ground from the upper regions. But the chief source of the difference is yet a mystery.

"We append a specimen of the rainfalls at different places:—

"TABLE OF RAINFALLS (AVERAGE ANNUAL).

| Names. | Inches. | Names. | Inches. |
|---|---|---|---|
| London (Greenwich) | 24·2 | Marseilles | 20·3 |
| Manchester | 35·5 | Madrid | 15·1 |
| Edinburgh | 25·8 | Lisbon | 27·5 |
| Glasgow | 43·2 | Milan | 39·8 |
| Glencroe | 127·7 | Rome | 31·5 |
| Aberdeen | 27·8 | Athens | 15·1 |
| Dublin | 27·7 | Jerusalem | 18·5 |
| Cork | 35·5 | Alexandria | 10·1 |
| Copenhagen | 23·3 | Calcutta | 66·0 |
| Brussels | 28·1 | Bombay | 76·2 |
| Paris | 19·9 | Madras | 56·3 |
| Pau | 46·8 | Melbourne | 25·7 |

The most remarkable rainfall in the world occurs at Cherrapoonjee, in the Khasyah Mountains; the average is 499·3 inches. At Akyab, on the Arracan coast (the famous rice district), the average is 204 inches, nearly half this quantity falling in the course of two months. The greatest rainfall in this country is found at Seathwaite, in the English lake district; its average is 145·1 inches. The *least* rainfall in the world of which we have any record is at Suez, 1·3 inch."

28. "*Snow—Snow-crystals.*—When the temperature of the air is below 32° F., the vesicles of vapour become frozen, and in uniting together become heavier than the air, and fall as *snow.* The flakes are sometimes small, at other times large, their size depending upon the amount of moisture and the extent to which the low temperature prevails. Should the flakes, in their descent, encounter warm strata of air, a partial fusion takes place, and they fall in a half-melted state, forming *sleet.*

Examined with the microscope, snow presents a very beautiful appearance; it is formed of a number of distinct and transparent crystals of ice, which are observed to be grouped together in a variety of ways. Fig. 18 exhibits some of the different forms of snow-crystals which are found." *

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BY

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LECTURER ON NATURAL PHILOSOPHY, EDINBURGH

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# JOHNSTON'S

# ILLUSTRATIONS OF LIGHT AND HEAT.

## *HEAT* (*PART II.*)

*N.B.*—The numbers of the paragraphs do not correspond with the numbers of the diagrams.

1. "*Capacity for Heat.*—Bodies differ from each other in regard to their *capacity* for heat—that is, in regard to the quantity of heat required to produce a stated effect, as, for example, to raise them 1° F. or 1° C. In order to measure or compare the capacities of different bodies for heat, it is necessary to adopt some standard or unit. It is customary in this country to adopt as the unit, *the quantity of heat required to raise* 1 *lb. of water* 1° *C.* at the standard temperature. It is called the *thermal* unit. We infer, therefore, that if a certain quantity of heat raise 1 lb. of water at the standard temperature 1° C., twice that quantity will be required to raise 2 lbs. three times that quantity 3 lbs., and so on.

"If we take a pound of water at the standard temperature, and 1 lb. of mercury at the same temperature, we find experimentally that the water requires thirty times as much heat to raise it 1° C. as the mercury. The capacity of water for heat is therefore said to be thirty times that of mercury.

2. "*Specific Heat.*—By the *specific* heat of a body is meant, *the relation between the quantity of heat required to raise the body, and that required to raise an equal weight of water, through* 1° *C.* at the standard temperature. Thus, referring to the case of mercury mentioned above, the specific heat of mercury will be expressed by the fraction $\frac{1}{30}$ or ·03. Again, when it is stated that the specific heat of copper is ·095, we mean that the quantity of heat required to raise copper 1° C. at the standard temperature is $\frac{95}{1000}$, or $\frac{19}{200}$ of that required to raise an *equal* weight of water 1° C., or, which is the same thing, the quantity of heat in the former case is to that in the latter as 19 to 200.

"It is of importance to adopt a *particular* temperature in stating the specific heats of bodies, for it is found that these *increase with the temperature.* In the case of liquids this variation is more manifest than in solids. With water, however, the increase is found to be *less* than in solids."

3. "*Latent Heat.*—During the passage of a body from the solid to the liquid state, or from the liquid to the gaseous state, its temperature remains *constant*, whatever be the intensity of the heating source. The heat which the body receives in its *transition state* does not affect the thermometer, does not manifest itself; and on this account it is called 'latent.' We may define *latent heat*, therefore, as *the quantity of heat which disappears or is lost to thermometric measurement, when the molecular constitution of a body is being changed.*

"Thus if we take a block of ice, say at -10° C., and apply heat to it, its temperature rises till it comes up to 0° C. At this point the temperature remains stationary until the last particle of ice is melted. When this takes place the temperature again rises till it reaches 100° C., when it once more remains stationary, the water then gradually passing off in the form of steam.

"(1.) *Water.*—If 1 lb. of water at 80° C. be mixed with

1 lb. of water at 0°, the temperature of the mixture is 40° C. But if 1 lb. of water at 80° C. be mixed with 1 lb. of pounded ice at 0°, there will result 2 lbs. of water at 0° C. It follows, therefore, that 1 lb. of ice at 0° C., in being changed into 1 lb. of water at 0° C., requires as much heat as would raise 1 lb. of water through 80° C., or, which is the same thing, as would raise 80 lbs. of water 1° C. Consequently, the number 80° C. (144° F.) expresses the latent heat of water or of the fusion of ice.

"(2.) *Steam.*—The latent heat of steam may be determined by observing the time required to raise a given quantity of water through a certain number of degrees, and then comparing this with the time between the commencement of boiling and the total evaporation of the water. It has been estimated at 540° C. (972° F.), implying that during the conversion of 1 lb. of water at 100° C. into 1 lb. of steam at the same temperature, as much heat is imparted as would raise 540 lbs. of water 1° C.

"The latent heat of steam is of service in cookery. Vegetables and meat are often cooked by allowing the steam from boiling water to pass through them; in doing so, the steam becomes condensed and parts with its latent heat. We can easily understand from this the severity of a scald from steam."*

4. *Ice Calorimeter.*—This apparatus was invented for the purpose of determining the specific heats of bodies. It is represented in section in fig. 1.

"It consists of three tin vessels, one within the other, the spaces *A*, *B*, between being filled up with pounded ice at 0° C. The body, whose specific heat is to be determined, is placed in the central one. There are two stopcocks *E*, *D*, for running off the water caused by the fusion of the ice on the part of the surrounding atmosphere and the heated body, respectively. In order to use it, the body of weight *W*, suppose, being raised to a given temperature *t*, is quickly placed in the central vessel, and allowed to remain

* Lees' Advanced Acoustics, Light, and Heat.

there till its temperature sinks to 0° C. The water resulting from the fusion of the ice is then drawn off at the stopcock $D$ and weighed. Let this weight be $w$. Now, as it requires 80° C. of heat to convert a pound of ice at 0° C. into water at 0° C. (see par. 3), the quantity of heat absorbed by the collected water will be expressed by $80 \times w$; whilst the quantity of heat given out by the body will be expressed by $W \times t \times x$, where $x$ is the specific heat required. We have therefore the equation, $W \times t \times x = 80\ w$; hence $x = \frac{80\ w}{W\ t}$.

"A certain amount of error results in the use of this instrument, from the fact that all the water does not escape; part of it adheres to the ice in its half-melted state.

5. "*Table of Specific Heats.*—The following table gives the specific heats of certain bodies, as determined by Regnault:—

MEAN SPECIFIC HEATS (BETWEEN 0° C. AND 100° C.).

| | | | |
|---|---|---|---|
| Water | 1·0050 | Copper | ·0951 |
| Mercury | ·0333 | Silver | ·0570 |
| Wood charcoal | ·2411 | Tin | ·0562 |
| Sulphur | ·2026 | Gold | ·0324 |
| Iron | ·1138 | Platinum | ·0324 |
| Zinc | ·0955 | Lead | ·0314 |

"Of all substances, *water* possesses the greatest capacity for heat, and therefore also parts with the greatest amount of heat when cooled down through a given range of temperature. This property is largely utilized in practice, as, for example, in the heating of buildings by hot water, and in feet-warmers in beds or railway carriages.

"The high specific heat of water plays an important part in the economy of nature. The specific heat of air has been found to be nearly 4·2 times *less* than that of water. It follows,

therefore, that 1 lb. of water in losing 1° C., would warm 4·2 lbs. of air 1° C. But water is 770 times as heavy as air; hence, comparing equal volumes, a cubic foot of water in losing 1° C. would raise $770 \times 4{\cdot}2$, or 3234 cubic feet of air 1° C. We see from this 'the great influence which the ocean must exert on the climate of a country. The heat of summer is stored up in the ocean, and slowly given out during the winter. Hence one cause of the absence of extremes in an island climate.' *

6. "*Experimental Illustration.*—The difference which subsists between bodies, in regard to their capacity for heat, may be strikingly shown by the following experiment: A cake of bees'-wax *C* is placed upon the ring of a chemical stand (fig. 2). Three balls of different metals, *A, D, B*—iron, copper, lead—are immersed in a bath of very hot oil till they all acquire its temperature. If now they be taken out and put upon the cake, they make their way through at different rates—the iron ball first, the copper next, and last of all the lead."

7. "*Cold of Evaporation.*—In the passage of water or any other liquid into vapour, there is a quantity of heat rendered latent. This heat is chiefly derived from the liquid itself, hence the temperature of the liquid is lowered. We have therefore the important fact that *cold is produced by evaporation.* The more rapidly evaporation proceeds, the degree of cold is the greater. If, for example, we take the three liquids, water, alcohol, and sulphuric ether, and put a drop of each successively on the hand, then waving the hand backwards and forwards in the air to hasten the evaporation, we find that the sensation of cold is least with the water, greater with the alcohol, and still greater with the ether. This arises from the rate of evaporation at the same temperature being different in the three liquids." †

* Tyndall on "Heat as a Mode of Motion," p. 143.

† Lees' Advanced Acoustics, Light, and Heat.

8. *Freezing by Evaporation.*—Evaporation may proceed so rapidly as to cause refrigeration.

Fig. 3 represents a simple apparatus for freezing water in this way. It is called the "Cryophorus." "It consists of two glass bulbs, *A* and *B*, connected by a tube. Water is put in the bulb *A*, and whilst a small orifice is left open at the bottom of the bulb *B*, the water is boiled; the steam escaping from the water chases out the air, and when this is all expelled, the orifice is closed by means of a blowpipe. On the water regaining its ordinary temperature, there is left in the apparatus nothing but a little water and its vapour. If now the bulb *A* be placed in a vessel to get rid of currents of air, whilst the other bulb *B* is plunged into a freezing mixture, such as snow and salt, the vapour as it escapes from the water is condensed, and in the course of half an hour or so the water in *A* begins to freeze." *

9. *Leslie's Experiment.*—Fig. 4 represents the apparatus by which Sir John Leslie succeeded in freezing water by evaporation. On the plate of an air-pump is placed a receiver *R*, which contains a small capsule of water *D*, mounted on a tripod with glass legs. The tripod stands in the middle of a flat dish *C*, which contains strong sulphuric acid. As the exhaustion of the air proceeds, the water evaporates, the vapour being immediately absorbed by the acid, till at length the remaining water begins to freeze and eventually becomes a solid mass.

The method of procuring ice in India affords an illustration of the same principle. Early in the cold weather, when the nights are clear, shallow unglazed earthenware pans filled with water are put out in the open air. Evaporation rapidly takes place, and this, aided by *radiation*, reduces the temperature of the water below the freezing point. A thin stratum of ice is thus formed on the surface. Before daybreak the thin cakes of ice are removed from the pans, and the accumulated mass, well hammered together, is stowed away in the icehouse.

* Lees' Advanced Acoustics, Light, and Heat.

Water-coolers, so much used in summer in this and other countries, owe their action to the same principle.

10. "*Convection of Heat.*—By the *convection* of heat is meant that process by which heat is *carried* and distributed through the mass of a fluid body by the actual motion of its own particles. Thus, water is boiled by convection. When heat is applied to a vessel of water, as in fig. 5, there are produced a series of ascending currents which carry the heat to the other parts of the liquid, until the water is raised to the boiling point.

"The currents may be exhibited by throwing into the liquid a little roughly-powdered amber, or common sawdust. A more striking experiment is to introduce carefully into the vessel, before the heat is applied, a strong solution of indigo, by means of a burette. The solution, from its density, remains at the bottom, and when the flame is applied, the dark fluid is seen to course upwards and downwards with the ascent and descent of the current, producing a very pretty effect.

"Winds are evidently just convection currents.

11. "*Applications of Convection.*—The principle of convection is taken advantage of in practice to a large extent. It is owing to convection that hot water is carried and distributed through different parts of a dwelling of modern construction. A high-pressure boiler, in connection with the cistern of the house, is fitted behind the kitchen fire, and pipes are led from this to the parts of the house to be supplied, returning again to the boiler. The warm water, aided by the elastic force of the steam, ascends the pipes, and may be drawn off at pleasure, whilst the surplus, becoming cool by radiation and contact with the pipes, returns to the boiler and gets an additional supply of heat. Thus a constant circulation is maintained. In the event of the accumulation of steam becoming such as to endanger the boiler, the precaution is adopted of leading a pipe directly from the boiler to the outside of the house. When the accumulation becomes dangerous, the water is expelled through this pipe, and

thus the boiler is relieved from any pressure *which would be apt to cause* rupture. A similar plan is often carried out in the heating of greenhouses. So also in the heating of public buildings, arrangements are adopted for maintaining a constant circulation of hot water through the pipes led into the different apartments."

12. "*Conduction of Heat.*—Heat is said to be conducted, or diffused by *conduction*, when it passes from molecule to molecule of a body.

"When the end of a poker is thrust into the fire it is heated; the molecules in contact with the fire are thrown into a state of more intense oscillation; the swinging atoms strike their neighbours, these again theirs, and thus the molecular music rings along the bar. The motion, in this instance, is communicated from atom to atom of the poker, and finally appears at its most distant end. . . .

"'This molecular transfer, which consists in each *atom* taking up the motion of its neighbours, and sending it to others, is called the *conduction* of heat.' *

"Bodies differ much from each other as regards their conducting power, or *conductivity*, as it is more generally called. Thus, metals as a class are the best conductors, though differing greatly from each other; whilst such bodies as wood, glass, wool, cotton, etc., are very imperfect conductors.

"All liquids and gases possess a very feeble conducting power. If, for example, a vessel of water be heated *from the top* by pouring gently on the surface a quantity of boiling oil, it is found that the heat makes its way downwards with extreme slowness, and it is only after a considerable time that the least rise in temperature is observable at the bottom of the vessel.

"Snow is a very imperfect conductor of heat. Travellers, when overtaken by a snowstorm, in some instances have had

* Tyndall on "Heat as a Mode of Motion," p. 191.

their lives preserved by taking shelter in a wreath of snow, before being benumbed by the cold. So also sheep have been taken out alive, though buried amidst snow for some time.

"The Esquimaux, it is said, construct their winter huts of snow. They shape the snow into large hard masses, which they place upon each other as our masons do stones; they then pour into the crevices ice-cold water, which upon freezing unites the whole into one solid mass. The inside being covered with the skins of animals, a comfortable dwelling is thus provided.

"This quality of snow is not without its use in the general economy of nature. In severe climates, it prevents the earth from being so much cooled down as to endanger those germs of vegetation which await the return of spring.

13. "*Determination of Conductivity in Solids.*—Several methods have been proposed with a view to determine the conductivities of different substances. The method most commonly carried out, and probably the most accurate, is that suggested by Fourier. It consists in observing the *permanent distribution* of temperature in a bar of uniform width and thickness, having one of its ends exposed to a steady source of heat. Along the bar $B$ are drilled a series of holes (fig. 6), for the reception of the bulbs of so many thermometers. When the heating source $L$ is applied, the different thermometers begin to rise, and at rates dependent upon the material of the bar; but after a stated time, owing to the effects of radiation and convection from the cool surrounding air, they all maintain a steady temperature. The readings of the different thermometers are then noted. The same thing is done with bars of different material, that is, the times required for the *steady* indications of the thermometers, and the readings after those times are carefully noted. From these data the conductivities are determined. By this method, but using instead of thermo-

meters a modification of the thermo-electric pile, Wiedemann and Franz drew out the following table :—

CONDUCTIVITIES OF METALS.

| | | | |
|---|---|---|---|
| Silver | 100 | Iron | 12 |
| Copper | 74 | Lead | 9 |
| Gold | 53 | Platinum | 8 |
| Brass | 24 | German silver | 6 |
| Tin | 15 | Bismuth | 2 |

"It has been found that the numbers in the above table nearly express the conductivities of the different metals, also, for electricity. Forbes was the first to remark this; he further proved, experimentally, that the thermal conductivity of iron *diminishes* as the temperature rises." *

14. *Conductivity of Copper and Iron.*—Fig. 7 shows an arrangement by which the difference between the conductivities of copper and iron may be illustrated.

Two bars of these metals, *C* and *I*, are adjusted as in the diagram. Underneath the bars are cemented by wax a series of wooden balls at equal distances. When the ends are heated by a lamp *L*, the heat is propagated more rapidly along the copper than the iron—the result is that the wax is more readily melted, and a greater number of the balls fall off from the former bar than from the latter in the same time.

15. "*Clothing.*—As the object of clothing is to prevent the escape of heat from the body, we must of course select those substances as articles of dress which offer resistance to the passage of heat, or such as are bad conductors. The common notion that there is natural warmth in any material is quite a wrong one. There is really no more natural heat in a piece of flannel than there is in a piece of lead. Flannel is an excellent

* Lees' Advanced Acoustics, Light, and Heat.

covering for a man in winter; it is nevertheless also the best substance for wrapping round ice to prevent it melting in summer. In the former case the source of heat being within, the flannel prevents the escape of heat, and thus contributes largely to warmth ; in the latter case, the source of heat is from without, and the flannel being a bad conductor effectually prevents the passage of heat into the ice.

"There being therefore no such thing as natural warmth in any material, it is evident that the lower the temperature to which we are exposed, the greater the waste of animal heat would be; hence in cold weather it becomes necessary to surround the body with such materials as are the worst conductors of heat. Now, according to experiment, fur is the worst conductor, and therefore the warmest covering; next to it is wool, fabricated into the different textures of flannel and cloth; next are cotton, linen, and silk, which being better conductors, form therefore a comparatively cool covering, and are fit only for the higher temperatures of summer.

"Air is a bad conductor of heat; hence loose clothing is warmer than we are apt to imagine.

16. "*Sensations of Heat and Cold.*—The different sensations of heat and cold, which we continually experience in *touching* bodies, arise altogether from conduction. When two bodies of different temperatures are placed in contact, the warmer parts with its heat to the colder, until they both acquire the same temperature. There is a constant tendency towards an *equilibrium of temperature.* Suppose, then, that a person in a room without a fire were to touch first the carpet, then the table, then the wall, and lastly the fender, he would consider each of them colder and colder in succession. Why? The reason is simply this: the carpet being a bad conductor, carries little heat off from the hand; the table is a better conductor, and thus feels colder; the wall is a better conductor still, and therefore feels still colder; but the fender is the best conductor of

the whole, and accordingly it carries off the heat rapidly, giving thereby the most powerful sensation.

17. "*Combustion.*—Combustion, such as we have it in our coal, in our gas and candle flames, is due to the chemical union of the oxygen of the air with the substances present in these.

"*Coal-gas* is a chemical combination of carbon and hydrogen. When the jet of escaping gas is ignited, 'the oxygen of the air unites with the hydrogen, and sets the carbon free. Innumerable solid particles of carbon thus scattered in the midst of the burning hydrogen, are raised to a state of intense incandescence: they become white-hot, and mainly to them the *light* of our lamps is due. The carbon, however, in due time, closes with the oxygen, and becomes, or ought to become, carbonic acid; but in passing from the hydrogen, with which it was first combined, to the oxygen with which it enters into final union, it exists for a time in the solid state, and then gives us the splendour of its light.' Within the flame there is a core of unburnt gas.

"'The combustion of a *candle* is the same in principle as that of a jet of gas. On igniting the wick, it burns, melts the tallow at its base, the liquid ascends through the wick by capillary attraction, it is converted by the heat into vapour, and this vapour is a hydro-carbon, which burns exactly like the gas.' *

18. "*Structure of a Candle-Flame.*—It is to Sir Humphry Davy that we owe our knowledge of the precise theory and constitution of flame. The structure of a candle-flame *F* will be understood from fig. 8. It consists of three parts: (1) the space occupied by the unburnt vapour; (2) the luminous zone or area where the carbon particles are in a white-hot, glowing state; (3) the area of complete combustion, from which the greatest amount of heat is evolved. The presence of unburnt vapour

* Tyndall on "Heat as a Mode of Motion," pp. 46, 47.

within may be shown by placing a small glass tube *T*, as in the figure. The vapour escapes through the tube, and may be ignited at the other end.

"The same thing may be shown by lowering a piece of white paper upon the flame till it nearly touches the wick. A blackened or charred ring is formed upon the paper, whilst within the ring the paper is unaffected.

19. "*Experiments with Wire Gauze.*—If a piece of fine wire gauze *G'* be lowered upon a gas-jet *B*, the flame *F'* spreads out below (fig. 9), but is unable to penetrate the meshes of the gauze. This is owing to the conduction of the heat by the gauze, in consequence of which the gas that escapes through cannot become ignited. On placing the gauze *G close* upon the top of the burner and lighting the gas, the flame *F* may be lifted off by gently raising the gauze, and eventually extinguished.

"Another striking experiment is to pour flaming spirits of wine upon a piece of gauze; most of the fluid drops through, leaving the flame burning upon the gauze." *

20. *The Safety Lamp.*—The "Davy Lamp," so much used in mining operations, is constructed on this principle. It consists of an oil-lamp enclosed within a double cylinder of gauze (fig. 10). Three uprights, *A*, *B*, *C*, connect the top *L* with the base, and serve as a protection to the gauze cylinder. The tube *T* is where the oil is poured in.

Notwithstanding the compulsory use of this lamp in all coal mines, we have ever and again to lament the occurrence of explosions. These sad disasters are too often the result of carelessness on the part of the miners in striking a light for their pipes, or in using skeleton keys to open up the lamp for the purpose of better illumination, thus exposing the naked flame to the explosive gas. A sudden draught or rush of gas on the closed lamp is probably the more frequent cause.

* Lees' Advanced Acoustics, Light, and Heat.

21. "*Bunsen Lamp.*—The luminosity of flames, as we have seen, is mainly due to the existence of solid carbon particles. Hence when a large quantity of air is allowed to mix with them their combustion is quickened, and heat is developed at the expense of intensity of light. This is what is effected by a *Bunsen lamp*, so much used in chemical and physical laboratories. It is represented in fig. 11. The gas, escaping from a central burner *J*, up the tube, draws with it a quantity of air through the small holes near the base. The mixture of gas and air is then ignited at the top of the tube *B*, and burns with a feeble light, but evolves considerable heat, owing to the complete combustion of the carbon. If the small holes be closed, the flame assumes its ordinary appearance." *

22. "*Metal Fire.*"—The principle of the Bunsen lamp is ingeniously taken advantage of in "Bateman's Patent Metal Fire," recently introduced. It is sketched in fig. 12.

The pipe conveying the gas is enclosed in an outer tube, which has an opening (at the bend) for the free admission of air. The gas escapes through a series of circular apertures in the side of the cylindrical casing, and being well intermingled with air, is wholly consumed. The heat thus generated is communicated to rings of twisted iron wire, surmounted with a cap also of twisted wire. Shortly after the gas is ignited the iron wire and the mounted cap glow with intense heat, and radiate most effectively. It is necessary to have a good pressure of gas, and to renew the rings of wire from time to time as they get wasted and clogged with residue. Occasional washing, also, is desirable.

The contrivance is well adapted for the heating of lobbies in private dwellings, and with proper attention does not give any disagreeable odour. The cost of gas consumed is estimated at 4½d. for twenty-four hours.

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23. *Reflexion of Heat.*—Heat, like light, is capable of reflexion, and follows the same law.

The reflexion of heat is well illustrated by the apparatus represented in fig. 13. Two metallic reflectors *R*, *R'*, "mounted on stands, are set directly opposite each other. A white-hot iron ball *B* is placed at the principal focus of one of the reflectors; if now a piece of phosphorus *P* be placed in the focus of the other reflector, it bursts into flame, being fired by the heat emitted from the ball, which has been concentrated by the reflectors at that point.

"The reflective powers of substances vary considerably. According to Leslie's experiments the greatest reflexion takes place from bright and polished metallic surfaces. Should the surface be rough or tarnished, the amount of reflexion is much diminished. Glass coated with lamp-black, and white paper, reflect very feebly.

"It is said of Archimedes of old, that he set fire to the Roman fleet, during the siege of Syracuse, by means of burning mirrors. Modern experiments have shown that this was quite possible. By the use of large metallic reflectors the sun's rays have been so concentrated as to ignite wood at some distance. Large reflectors have been applied also to the cooking of food by solar heat.

24. "*Application to Common Experience.*—We may gather from the foregoing principles many useful and important hints regarding facts of everyday life. Thus we learn why the polished fireirons, which stand beside a fire, are not inconveniently heated. The heat which falls upon them is reflected in a great measure by the polished metal. Should they be allowed to become tarnished the reflexion is not so complete, and they become heated. The polish, therefore, of fireirons is not only ornamental but contributes largely to comfort in handling them. It is of advantage that the interior of a screen placed behind roasting meat be kept clean and polished, for then it is a good reflector, and aids materially the cooking process.

"Certain parts of a steam-engine ought to be highly polished, not so much for appearance' sake, but as a most effectual means of retaining the heat of the steam, thus preventing loss by condensation. A stove ought to have its exterior surface rough and well blackened, so as to allow radiation to take place freely. A tea-kettle, on the other hand, ought to be well brightened up so as to diminish radiation, and thus tend to retain the heat of the water as long as possible. Should a 'cozy' be used for a teapot, it ought to be made to fit loosely, for then the radiation is much impeded." *

25. *The Radiometer.*—Fig. 14 exhibits a common form of this remarkable instrument. Four small vanes *A* of mica, blackened on one side, are connected to the ends of wires attached to a vertical spindle, which moves in glass sockets *B* and *C*. The whole is confined in a vessel nearly exhausted of air.

On exposing the apparatus to good sunlight, to a live ember from a fire, or even to a lighted lucifer match, the vane system rotates—and with considerable velocity if the source of heat be strong.

A difference of opinion still exists among physicists as to the precise principle of its action. The more general theory seems to be that the rotation is due to the internal movements of the molecules of the residual gas—that there is a *greater* reaction from these molecules on the blackened side of the mica than on the bright side. In a vacuum no motion takes place, because there is *no* reaction-force; neither is there any motion when the vessel is full of air, because the reaction-force is too small to overcome the resistance of friction and the air. It is only when the rarefaction is sufficiently complete that rotation ensues.

26. *The Photophone.*—This remarkable instrument is the recent invention of Professor Graham Bell. Its object is to convey articulate speech or musical sounds to a *distance* by means of light.

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Fig. 15 exhibits the form of the instrument as adapted for speech—it is called the "articulating photophone." A mirror *M* receives the rays from the sun, and reflects them towards a lens *L*, by which they are concentrated. A little beyond the focus of the lens is placed a small disc of glass *G*, silvered on one side, and mounted in a frame *T*. The disc is in communication with an indiarubber tube terminated with a mouthpiece. This part of the apparatus forms the "transmitter." The rays of light reflected from the silver surface of the glass disc *G* pass through a second lens *L′*, by which they are reduced nearly to a state of parallelism. They are then received upon a parabolic reflector *R*, in the focus of which is placed a selenium cell *S*. This cell is put in circuit with a battery *B*, and a pair of telephones *T*, *T*. The reflector *R* with its appendages constitutes the "receiver."

On speaking into the mouthpiece at *T*, the glass disc *G* is thrown into vibration. This causes a fluctuation on the intensity of the rays of light which fall upon the selenium, and as this substance is peculiarly sensitive to light, *increasing or decreasing its conductivity for electricity*, a variable action is produced on the telephone discs. The result is that there are reproduced at the receiver the same vibrations as actuated the glass disc at the transmitter, and the very words of a speaker are thereby rendered audible.

The instrument may yet be said to be in its infancy, but the results that have been already obtained by it are surprising.

27. *Heat developed by Friction.*—"We have many familiar examples of the development of heat by friction. The ready ignition of a lucifer match in this way is due to the fact that the chemical material at the tip is thrown into combustion by a small quantity of heat. The ancient method of lighting a fire is said to have been to thrust the end of a round stick between two pieces of wood, and to make it rotate rapidly by means of a bow and a string of catgut. A common method among

savages consists simply of rubbing briskly upon each other two pieces of a particular kind of wood which have been prepared and well dried. In the case of striking flint and steel together, in the grinding of a knife, or in the quick stoppage of a railway train as it nears a station, the sparks of fire are really due to the minute metallic particles which have become detached, being raised by the excessive friction to a glowing state. The heating of a saw working through wood, the warmth produced in the hands when rubbed together, the heating of the axles of wheels when lubricants are neglected, are all examples of the same thing.

"Fig. 16 represents an apparatus devised by Tyndall which illustrates the same truth. A brass tube *T* is placed on a whirling stand *A, D, S;* it is filled with water, and corked up. Two pieces of wood, *B*, with a groove cut in each of them, are jointed with a hinge, and are made to embrace the tube with sufficient tightness. The tube being made to rotate rapidly, the friction develops such an amount of heat as to boil the water, and in a short time the cork *C* is driven out with a loud report.

"Davy was the first to perform the interesting experiment of fusing ice by rubbing two pieces together.

"In all such cases the work performed in overcoming the friction expresses itself in the form of heat; and the greater the amount of the work—in other words, the greater the muscular effort expended, the greater the development of heat."

28. "*Mechanical Equivalent of Heat.*—It is to Joule we owe the determination of the exact numerical relation between heat and work. He devised the apparatus in fig. 17 for this purpose. *B* is a copper vessel filled with water, in which there revolves a system of paddles, one of which *P* is represented at the side. The common axis of the paddles is connected by a movable pin *p*, with a vertical cylinder *A*. From this there

passes a cord in connection with a pulley *C*, moving on friction wheels, and from the axis of which there depends a weight *W*. The descent of this weight is indicated on a graduated scale *S* in feet and inches. The weight being wound up, which can be done by detaching the pin *p*, and thus not moving the paddles, the pin is replaced, and the weight allowed to descend; this causes the paddles to revolve; they agitate the water and raise its temperature. This operation being repeated several times, the temperature of the water is then noted, as given by the thermometer *t* placed in the vessel. To prevent the rotation of the water, the paddles pass through fixed partitions in the vessel, resembling in form the paddles themselves.

"In this way, and by a number of very careful experiments, Joule established the fact that *to raise* 1 *lb. of water* 1° *F. requires the expenditure of as much work as would raise* 772 *lbs. one foot*, or, which is the same thing, 1 *lb.* 772 *feet.* This number, '772 * *foot-pounds*,' is therefore known as the *mechanical equivalent of heat.* If we adopt the centigrade scale, the number is 1390 foot-pounds, which, of course, implies that the amount of heat required to raise 1 lb. of water 1° C., is such as, when applied mechanically, would lift 1390 lbs. one foot.

"Joule further showed that *the absolute amount of heat generated by a given expenditure of work is fixed and invariable.* He was led to lay down this principle by experimenting in various ways. For example, in causing discs of cast iron to rub upon each other, he measured the amount of heat developed, and the force expended in overcoming the friction. Again, in urging water through capillary tubes, he did the same thing. He found, in such cases, that the above principle, making due

* Some recent experiments under the auspices of the British Association have been undertaken by Dr. Joule with the view to test this result. The *mean* of 60 experiments gave 772·2 *foot-pounds.*

allowance for difference in the specific heats of the substances, was accurately correct." *

29. *The Eolipile.*—This instrument was invented by Hero of Alexandria, B.C. 130. It is the first machine constructed to generate motion by steam.

It consists of a hollow metallic globe *S* (fig. 18) capable of rotating upon an axis. Two small tubes *A* and *B* are set directly opposite each other, with contrary orifices. Water being introduced into the globe, and a lamp *L* applied to it, steam is generated in a short time, which, escaping at the orifices, generates a reactionary force sufficient to cause rotation.

30. *The Steam-Engine.*—Fig. 19 is a sectional drawing of the chief parts of the steam-engine as used at the present day. The names and uses of the different parts are described below.

*A* is the working beam; *C*, the cylinder in which the piston *P* works; *S*, the steam-pipe in communication with the boiler; *D*, the D-valve, acted upon by a system of levers *L* worked by the eccentric *N*, which is connected with the driving axle. This valve regulates the passage of the steam to one side or other of the piston, and also its passage to the condenser *E*, when the piston has been moved to the top or bottom of the cylinder. In the condenser *E* a jet of water is allowed to play for the purpose of hastening the condensation of the steam, and is controlled by a conical valve attached to the end of a vertical spindle; *F*, the hot-water pump for removing the condensation water from the condenser; *G*, the cold-water pump for supplying the spaces surrounding the condenser and hot-water pump with cold water; *O*, *H*, the "parallel-motion" arrangement, by which the piston rods of the cylinder and hot-water pump are made to move vertically; *R*, the connecting rod; *B*, the crank rigidly fixed to the driving axle; *W*, the flywheel, by which the variable effect of the connecting-rod on the crank is counteracted. In connection with the steam-pipe is set the "governor"

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(not shown in the drawing), an arrangement by which the quantity of steam passing through the steam-pipe is regulated, and made to suit the demands of the engine.

31. *The Locomotive.*—Fig. 20 is a sectional drawing of the chief parts of the ordinary locomotive.

*B, B*, is the boiler, traversed by a number of tubes *T, T*, for the purpose of heating the water as speedily as possible; *S*, the steam-pipe led up into the steam dome *D*. The steam by this arrangement is so far free of "priming" as it is called—that is, of watery particles cast up by the ebullition. The steam-pipe divides at the remote end into two branches supplying the two cylinders, one of which only, *C*, is shown. *R* is the connecting-rod jointed to the crank *E*, which is fixed to the axis of the driving-wheel *W*. The steam after performing its work in the cylinder escapes through *G* at the base of the funnel *F*. This arrangement greatly facilitates the production of steam, for thereby the draught is increased, and the combustion of the fuel hastened. The speed of the locomotive exercises therefore an important control over the rate at which the steam is generated—the faster the locomotive goes, the more rapid is the supply of steam. The passage of the steam into the steam-pipe *S* is regulated by a valve *V*, worked by a handle *H*. *V'* is the D-valve arrangement worked by the engine itself by means of a pair of eccentrics, one of which controls the motion *forwards* and the other *backwards*. In order to secure uniformity in the motion of the machine, the two cranks in connection with the connecting-rods are set at right angles to each other. The projection in the boiler between *B, B*, is the man-hole, for the purpose of cleaning out the inside of the boiler when necessary. The other two projections represented in the diagram are for the insertion of safety-valves, one of which is within the control of the engine-driver, and the other locked up, so that the pressure of steam applied cannot exceed what is consistent with the strength of the boiler.